DOWNPULL CHARACTERISTICS OF VERTICAL LIFT AND TAINTER GATES IN CLOSED CONDUITS

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By

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to my father

CERTIFICATE

The thesis ''Downpull Characteristics of Vertical Lift and Tainter Gates in Closed Conduits'' by Shri R.L. Sharma is hereby approved as a creditable report on research carried out and presented in a manner which warrants its acceptance as a prerequisite for the degree of Master of Technology. The work has been carried out under my supervision and has not been submitted elsewhere for a degree.

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LIST OF SYMBOLS

The following symbols are used in this thesis:

A = cross-sectional area of the conduit;

a' = ratio of the area of the venacontracta to the cross sectional area of the conduit;

a = height of the trunnion axis for the tainter gate above the bottom of the conduit;

B = width of the gate;

C_c = coefficient of contraction;

C_d = discharge coefficient;

C_e = loss coefficient for entrance head loss;

D = diameter of the circular conduit;

d = gate thickness;

e = projection of the skinplate;

g = gravitational acceleration;

H = total height in the reservoir;

H_e = entrance head loss;

h_G = height of water level in the gate chamber above the top of the conduit ;

h_j = piezometric head at venacontracta;

h_i = piezometric head at a point on the gate bottom;

h_T = piezometric head on the top surface of the gate;

K = factor, compensating for departure from hydrostatic pressure distribution;

P = downpull resulting from the difference between the pressures acting on the top and the bottom surfaces of the gate;

P_i = pressure intensity at a point on the gate bottom;

Q = total rate of flow at gate opening y;

R = Reynolds number of the flow ($R = V_J d/\nu$);

r = (i) radius of curvature for the rounding of the gate lip (Fig. 3.3) for the vertical kift gate and

(ii) radius of curvature of the skin plate for radial gate (Fig. 3.4);

V_J = velocity of the contracted jet issuing from underneath the gate;

v = mean velocity;

y = gate opening;

y_o = conduit height;

w = specific weight of water

θ = angle of inclination of the bottom surface of the gate;

K_B = dimensionless piezometric head at a point of the bottom surface of the gate = $\dfrac{(h_i - h)}{V_J^2/2g}$;

$\bar{K}_B$, $\bar{K}_T$ = dimensionless piezometric head on the bottom and top surface of the gate;

$$= \frac{h_i - h}{V_J^2/2g} \text{ and } \frac{h_T - h}{V_J^2/2g};$$

ν = kinematic viscosity of water; and

γ_ω = density of water.

ABSTRACT

The effect of the variation of the geometric parameters like gate geometry and relative gate opening, flow parameters like jet Reynolds number and dimensionless gate chamber water level for submerged flow are studied and it has been found that the effect of Reynolds number is secondary whereas the effect of other parameters is primary. Relative gate opening is varied from 0.1 to 0.8 at various Reynolds numbers and effect on downpull parameters $\overline{K}_T$, $\overline{K}_B$ and $(\overline{K}_T - \overline{K}_B)$ is studied. For vertical lift gate $(\overline{K}_T - \overline{K}_B)$ is found to be positive at all gate openings indicating downpull while for tainter gates $(\overline{K}_T - \overline{K}_B)$ is found to be negative always indicating uplift force.

CHAPTER I

INTRODUCTION

Vertical lift gates are among the most widely used high-head gates for flow regulation or emergency closure of large out lets and conduits because of the many advantages they offer in construction and maintenance. Two arrangements may be distinguished. The first arrangement consists in operating the gate in a gate well located within a conduit transition as shown in Fig. 1(a). This type of gate is known as tunnel-type gate while in the second arrangement the gate is operated in a gate well located on the upstream face of a dam or an intake structure known as face-type gate.

In either case, the pressure along the bottom surface of the gate is reduced during operation as a result of the high efflux velocities, whereas the pressure on the upper portion of the gate is only slightly changed from static conditions. The resulting pressure difference induces an unbalanced downward force which often exceeds the dead weight of the gate considerably. The magnitude of this force, commonly known as the hydraulic downpull, affects the dimensioning of the hoist mechanism and, hence, the safety of the entire project.

In the absence of any flow, a gate that is completely submerged is subject to hydrostatic pressure that produces a buoyant force. This static condition is characterised by a uniform value of the piezometric head. The non-uniform distribution of piezometric head that is observed under flow conditions is due to the reduction of pressure. Downpull is primarily of concern to the designer of gate hoisting equipment. He must take into account the weight of the gate, the buoyant force, frictional forces, and downpull. Downpull may be many times greater than the weight of gate, and under some conditions it may become negative, indicating an up lift. It is taken positive in the direction of gate closure. The forces due to friction can be easily computed assuming the well established coefficient of friction, so also the weight of the gate and upward thrust can be worked out but there are no mathematical/emperical formulae or design curves available which can help compute hydraulic downpull forces. This has therefore, to be determined experimentlly by means of scale models.

Although extensive downpull studies have been conducted in the past on vertical lift gates, there is no satisfactory method available for adapting these

findings to new projects, and specific model tests are still indispensable. The difficulty in applying previous experimental work lies in the fact that not only the boundary geometry, but also the flow conditions under which the gate is operated, vary from project to project.

The main portion of downpull results from the difference between the pressure forces acting on the top and bottom surfaces of the gate, the residual portion acts on the seals and other protrusions of the gate. For downpull analysis it is essential to predict the pressure forces effective on the top and bottom of the gate, each of which can be expressed by the ratio $\bar{K}$ of the respective mean piezometric head to a reference velocity head. The significance of the $\bar{K}$ - terms so obtained is their independence of the absolute magnitude of the flow velocities. Once determined they can be used in combination with any flow condition so long as the boundary geometry is similar, provided the Reynolds number is sufficiently high. This condition is usually satisfied for high-head gates. The downpull analysis is thus reduced to the evaluation of the $\bar{K}$-terms for a particular geometry configuration and the determination of the reference velocity head for a particular flow condition.

The latter part of the problem is approached semi-empirically. By the one-dimensional method of analysis, an equation is derived expressing the rate of flow past the gate as a function of the gate opening and width, the total head over the conduit inlet, and the conditions of control in the conduit downstream from the gate. Such effects upon the rate of flow as stem from the flow contraction at the gate, the entrance head loss, the shape and the surface roughness of the transition downstream from the gate are, considered with the aid of empirical coefficients.

Information on downpull characteristics of tainter gates is not available in literature.

So experimental studies have been conducted on one vertical lift gate and two tainter gates to determine their downpull characteristics. The studies on vertical lift gate have been conducted to compare the results with already published results.

CHAPTER II

LITERATURE REVIEW

2.1 TYPES OF GATES

Various types of underflow sluice gates (16) are commonly used to regulate flows in hydraulic structures under high heads. Through the years great many types of gates have been designed and built but only a relatively few types have survived and are presently in use. Types of gates which are presently used for flow regulation in high-head installations are:

(i) Vertical lift gates and

(ii) Tainter gates.

These are the only two types which are specifically designed for throttling conditions to regulate flows. Wheel, roller-mounted, and cylinder gates (20) are also sometimes used for regulation, but are normally used only as fully opened or closed guard gates. Ring-follower gates, ring-seal gates, bulkhead gates, and stop logs are never used for throttling and regulating flow.

(i) Vertical lift gates:

In the early 1900's so-called 'high-pressure' slide gates, became the standard means for regulating

and shutting off the flow of water in the outlet works in dams. These gates are widely used high-head gates (21) for flow regulation or emergency **closure** of large outlets and conduits, because of many advantages they offer in construction and maintenance. By choosing suitable gate slots, upstream face and gate lips, these gates can be designed for regulation at heads of over 100 m. Slide gates are used for both guard and regulating service. Frequently two practically identical gates are bolted together in tandem. In such cases the upstream gate functions as the guard gate for the downstream regulating gate. The gates can be used either for free discharge into atmosphere or for submerged discharge in water. At heads above 66 m, fluidway surfaces and the bottom seating and sloping surfaces of the gate leaf should be stainless steel to avoid cavitation. The only practical limitations in the operation of slide gates for throttling is that they must not be operated at very small gate openings.

Basically, a slide gate consists of a leaf which is either closed by being positioned across the fluidway in the body or opened by being with drawn into the bonnet by a hoist mounted on the bonnet cover. In general, slide gates are operated by hydraulic hoists, mounted on

the bonnet cover. In the design of slide gates for high pressures and velocities, several critical design and fabrication requirements such as smoothness, straightness, proper leaf-slot geometry and the design of the bottom of the leaf to minimize downpull must be met (5,6,8, 10,12,18 etc.).

(ii) Tainter gates:

As reported in Engineering manual (7), the tainter gate is considered the most economical, and usually the most suitable, type of gate for flow regulation because of its simplicity, light weight, and low hoist-capacity requirements. A variety of types of tainter gate installations has been developed, but the original and maintenance cost can be held to a minimum only by careful selection. The hydrostatic forces acting on the gate skin plate have a radial resultant which passes through the gate, trannion or pivot. Thus they are capable of closing by their own weight. Another desirable feature with radial gates is that it needs no gate slots.

The principal elements (13) of a tainter gate structure are the skinplate assembly, the members supporting the skinplate assembly, the end frames, the trunnions and the anchorages.

Because of constant span under varing loading on the skin plate, the minimum thickness of skin plate should not be less than 8 mm. Carl C.H. (3) found that multiple wire ropes probably constitute the ideal hoisting medium because of their great elastic capability in absorbing the effects of differences in rope lengths. It was also found that single arm gates are more advantagous than with multiple arms. In order to obtain better all-round performance of tainter gate anchorages, post-tensioned type anchorages should be used.

2.2 FLOW CHARACTERISTICS

Characteristics of flow for vertical lift gates were studied by Naudascher et al.(12), Uppal, H.L.(19-21).They found that two states of flow are generally found to occur during their operation:

(i) Submerged flow and

(ii) Free flow.

The transition from one state of flow to the other occurs as a hydraulic jump approaches or with draws from the gate. The corresponding intermittent state of partially submerged flow is limited to an extremely small range of gate openings. For most installations of high-head gates the state of submerged flow is predominant during their

operation. In free surface case a jet of water issues from the gate with a free surface. Air gets entrained in the water and ventilation through an air inlet which must be provided if cavitation and vibrations are to be avoided. The piezometric head in the contracted section of Jet will then be given by the following equation

$$h = C_c y + \frac{\Delta P}{\gamma_w}$$

in which Δp is the difference between the pressure of air downstream from the gate and the atmospheric pressure at the reservoir. The rate of flow under the gate in both the cases, if no water is released above the gate is given by

$$Q = C_c \, yb \sqrt{2g(H - H_e - h)}$$

2.3 DOWNPULL CHARACTERISTICS

Laboratory studies have been made to determine the hydraulic downpull on several different types of vertical lift gate installations, but no efforts have been made to determine the hydraulic downpull on Tainter gates till now.

Simmon, W.P. (17) studied the effect of gate opening on downpull for a fixed wheel type of gate. He found that

maximum downpull on the gate occurred during submerged operation at about 7.62 cm opening. The downpull rapidly decreased as the opening increased. on the slide gate, the maximum downpull force occurred at about 45 per cent gate opening. Gate chamber pressures play a particularly important part in the case of slide gate, and in designs where leakage from the bonnet is permitted or encouraged to decrease the bonnet pressures, downpull will be materially reduced. The drainage or leakage can not be regarded as solution to the downpull problem as it may create other complications.

Naudascher, E., Smith, P.M., Singh, G., et al.(12,15,18) studied the effect of different geometric parameters on the downpull for a vertical lift gate. The details of the gate-lip geometry were found to be of minor influence as far as the mean downpull is concerned and of major influence on fluctuating downpull. While the mean downpull depends essentially on the overall parameter e/d, the fluctuation about a mean is a function of each one of the specific parameters r/d, e/d and θ. Separation is reduced and ultimately eliminated as the gate lip approaches either the floor or the roof of the conduit. The smaller the relative conduit height y_0/d, the less the tendency towards separation. An increase

in r/d or θ also reduces separation. It was found that for $y_o/d = 4$ and $r/d = 0.4$ the flow remains completely attached to the bottom surface provided the later is inclined at 30^o or more. Extremly flat lip shapes cause the flow to separate completely from the gate lip as reported by Naudascher (12).

From a constructional view point e/d should be as small as possible. Singh, G. and Paul, T.C. (18) observed that lip shapes appreciably alter the magnitude of hydraulic downpull and is one of the most important parameters in the design of high-head gates. U.S.B.R. design practice provides that in the case of vertical-lift fixed-wheel gates with vertical lip the length of lip should not exceed half the gate thickness when the lip is located on the downstream side. It has also been noticed (18) that if the upthrust at the bottom of the gates is excessive, to ensure safe closure of gates, improvements can be affected by reducing the lip length so that the ratio of lip length to gate thickness is not greater than 0.45 and not less than 0.42.

The hydraulic downpull studied by Singh, G. et al.(18) on the vertical lift fixed wheel emergency gate for the Pandoh-Baggi Control Works, with skin plate on the upstream

side and with its original length of lip giving e/d = 0.587 was negative at most of the gate openings. The magnitude of downpull measured was more than the weight of the gate. He found that the value of downpull decreases linearly as

$$P_{max} = 156.7 - 344.83\ e/d$$

and become positive for e/d ratio less than 0.46. Robert, G. Cox, et al. (6) considered in **their discussion** the effect of (**i**) gate clearances and venting on the hydraulic forces on the top of the gate, (ii) the effects of gate bottom geometry and venting on the hydraulic force on the bottom of the gate, (iii) the development of diamensionless parameters for design and (iv) the effects of gate bottom geometry and venting on the stability of the gate. **They gave** the following equation for hoist load on the gate.

$$P = W + A\,\gamma_w\,(d_f - u_f)$$

where P denotes the downpull in tons, W the dry weight of gate in tons, the cross sectional area of gate, and d_f and u_f are the downthrust and upthrust at top and bottom of the gate respectively.

In 1953, elaborate investigations were taken up in connection with the design of Emergency gate for Bhakra Dam

and the use of vertical lip on the downstream face and depression of 457.2 mm in the axis of the dam were suggested to minimize the hydraulic downpull. Uppal, H.L. (20). Suggested 45^{o} cut in the lip and **a depressed** base with arc shape of radius 7.62 cm to reduce the downpull.

So far several emperical formulae for the determination of discharge coefficient, pressure forces acting on the surface of Tainter gates (1) and for other geometric and structural designs (3,7,8, 10,13,14 etc.) are available, but no efforts have been made to determine the hydraulic downpull forces.

CHAPTER III

ANALYSIS

3.1 FLOW ANALYSIS

Two states of flow generally found to occur for most installations of high head gates are:

(i) Submerged flow;

(ii) Free flow.

Submerged flow is predominant during the operation of high head gates. In this case water Jet which issues beneath the gate is drowned by a standing eddy, while in case of free flow water jet issues from the gate with a free surface.

Since submerged flow is most predominant, study during the present experiments is confined to submerged flow only. The lines of total head and piezometric head for a conduit, under submerged conditions are illustrated in Fig. 1(a). The head loss between the reservoir and gate section is represented as overall entrance loss H_e in the form

$$H_e = C_e \frac{1}{2g} \left(\frac{Q}{A} \right)^2 \qquad (1)$$

and the rate of flow Q released by the gate is given as

$$Q = a'A\sqrt{2g(H-H_e - h)} \qquad (2)$$

in which

$$a' = \frac{C_c\ y\ b}{A} \qquad (3)$$

is the ratio of the cross sectional area $C_c yb$ of the fully contracted jet to the area A of the conduit section, and H and h are the total head in the reservoir and the piezometric head at any point in the contracted jet respectively. The velocity distribution in the contracted section of the jet is assumed to be uniform. With reference to Fig. 1(a), the velocity head in the contracted jet under the gate is expressed as

$$V_J^2/2g = H - H_e - h \qquad (4)$$

3.2 DOWNPULL ANALYSIS

For steady, irrotational flow the piezometric head along a boundary is completely defined by the distribution of velocity along the boundary relative to a reference velocity V_o and its magnitude. The distribution of relative velocity V/Vo and, hence, the distribution of piezometric head relative to the reference magnitude $V_o^2/2g$

depend on the flow pattern and other geometric parameters. It follows that the relative distribution of piezometric head is independent of the actual magnitude of velocity.

In general, the flow along the bottom surface of a high-head gate is continuously accelerated, and hence the departure from the conditions of irrotational flow is negligible. If $V_J^2/2g$ is selected as a significant reference,

$$K_B = \frac{\left(\frac{P_i}{\gamma_w}\right) + y_i - h}{V_J^2/2g} = \frac{h_i - h}{V_J^2/2g} \qquad (5)$$

Should also be independent of the actual magnitude of velocities, and it should be possible to relate a particular pressure distribution under the gate uniquely to a corresponding gate and conduit geometry (Fig. 1(b)). Integration of the relative distribution of piezometric head with respect to the gate thickness and the gate width yields

$$\bar{K}_B = \frac{1}{Bd} \int_0^d \int_0^B \frac{h_i - h}{V_J^2/2g} \, dB \, dx \qquad (6)$$

The piezometric head h_T on the top surface of the gate is generally constant, it can readily be integrated to yield

$$\overline{K}_T = \frac{1}{Bd} \int_0^d \int_0^B \frac{h_T - h}{V_J^2/2g} \, dB \, dx \approx \frac{h_T - h}{V_J^2/2g} \qquad (7)$$

Knowing the pertinent $\overline{K}$-values and the reference velocity V_J, downpull can be calculated. The primary portion of the downpull, resulting, from the difference of the integrated distribution of piezometric head along the top and the bottom surface of the gate, becomes

$$P = (\overline{K}_T - \overline{K}_B) \, Bd \, \gamma_w \, \frac{V_J^2}{2g} \qquad (8)$$

The residual portion of the downpull occurs on horizontal protrusions of the gate as the top seal.

3.3 DIMENSIONAL ANALYSIS

3.3.1 Vertical lift gate:

The geometric parameters for a vertical lift gate are shown in Figs. 1(a) and 1(b). From dimensional analysis, the distribution of piezometric head on the top and bottom surfaces of the gate can be expressed in the nondimensional functional form

$$\frac{h_T - h}{V_J^2/2g}, \; \frac{h_i - h}{V_J^2/2g} = \phi' \left[R, F, K, x/d, \frac{y(t)}{d}, \frac{y_o}{d}, \theta, \frac{e}{d}, \frac{r}{d}, \frac{B}{d} \right] \qquad (9)$$

in which R is the Reynolds number of flow defined as

$R = dV_J/\nu$ and y, y_o, θ, e, r and d are gate opening, conduit height, angle of inclination of the bottom surface of the gate, projection of the skin plate, radius of curvature for the rounding and gate thickness (Fig.1(b)) respectively.

In the present experiments, which were restricted to submerged flow, without cavitation, the Froude number F and the K had no effect. For the conditions of stationary gate positions $y(t) = y$ = constant, and for two-dimensional flow ($B/d \rightarrow \rightarrow \infty$) the above relationship reduces to

$$\bar{K}_T\ ,\ \ \bar{K}_B = \phi\ (R,\ y/y_o,\ y_o/d,\ \theta,\ e/d,\ r/d) \qquad (10)$$

The range of variation of these parameters in the present experiments was as follows:

$y_o/d = 4.0$

$\theta = 45^o$

$e/d = 0$

$r/d = 0.4$

R	y/y_o
0.3×10^5	0.1 to 0.8 with increments of 0.1
2.0×10^5	" " "
$1.7 \times 10^5 - 4.14 \times 10^5$	" " "

3.3.2 Tainter gate:

For tainter gate the geometric parameters are shown in Fig. 1(c). The distribution of piezometric head on top an bottom surface of a tainter gate, for two-dimensional flow and stationary gate positions can be expressed in non-dimensional functional form as

$$\bar{K}_T, \bar{K}_B = \phi\,(R,\ y/y_o, h_G/y_o,\ \theta\ ,\ a/y_o,\ r/y_o) \qquad (11)$$

The range of variation of these parameters for the present experiments was as follows:

a/y_o	r/y_o	θ	h_G/y_o	y/y_o	R
1.25	1.875	34^o	0.2 to 0.5 with increments of 0.1	0.1 to 0.8 with increments of 0.1	0.8×10^5 to 5.9×10^5
1.25	1.250	78^o	''	''	4.0×10^5 to 7.0×10^5

CHAPTER IV

EXPERIMENTAL DETAILS

4.1 EXPERIMENTAL EQUIPMENT

Experimental equipment used in the present investigation is shown in Fig. 2. The experiments were conducted in a steel conduit 30 cm in width, 30 cm in height, and 5.10 m long. Water was supplied to the conduit from a constant head overhead tank. A supply pipe line from the overhead tank fitted with a sluice valve to control the flow was connected to the head tank of the main conduit. The conduit was made of three portions:

(i) Entrance section;

(ii) Test section;

(iii) Exit section.

The entrance section as shown in Fig. 2 was 2.0 m long with its upstream end connected to the head tank and downstream end connected to the test section. The head tank was provided with one piezometer tapping at a height of 3 cm above the top surface of the conduit. Five piezometer tappings were provided in the entrance section. The test section was 60 cm long with a gate chamber 8.75 cm long,40 cm wide and 90 cm high (internal dimenions) for the vertical lift gate, while the test

section for Tainter gates was 60 cm long 30 cm wide and 90 cm high. Exit section was 2.5 m long and was provided with a sluice valve at the downstream end to ensure submerged flow.

Discharge was measured by a calibrated contracted sharp crested weir fixed in the drain as shown in Fig. 1. The discharge equation for the weir is

$$Q = C_e \frac{2}{3} \sqrt{2g} \ \ b_e \ h_e^{3/2}$$

where C_e is coefficient of discharge, be effective width in m, and he is effective head in m. C_e, b_e and h_e have been calculated as per ISI Code (22). The results obtained by this procedure tallied with the calibration data.

4.2 TEST MODELS

Three test models (one vertical lift gate and two tainter gates) were fabricated out of aluminium plate and rolled steel angles. The models were tested under suberged flow conditions.

The first model fabricated and tested was vertical lift gate as shown in Fig. 4(a) with a bottom inclination of $\theta = 45^{\circ}$. The gate was 7.62 cm thick and 30 cm wide. The downstream plate of the gate was 30 cm wide with 2.5 cm extra widening on each side so as to be fitted in the slots provided in the gate chamber. The gate was suspended vertically by a threaded shaft that passes through the

cover plate fixed at the top of the gate chamber. The gate was raised and lowered by turning a screw handle fixed to the shaft.

The vertical lift gate model was provided with 20 piezometer tappings - 9 on the sloping bottom portion, 5 on the centre line of upstream face and 6 on the downstream face. One piezometer tapping was provided on the gate chamber and one at 5.0 cm upstream from the gate, which gave the approximate stagnation pressure. 8 piezometer tappings were provided immediately downstream from the gate chamber with a c/c spacing of 3 cm to locate the position of the vena contracta of the jet issuing from beneath the gate. The first tapping was at a distance of 1.5 cm from the gate. Location of piezometer tappings for vertical lift gate is shown in Fig. 3(a).

The other models studied were tainter gates, each 30 cm wide and having radius of 57.15 cm and 37.5 cm respectively as shown in Figs. 4(b) and 4(c). The skin plate, 3.175 mm thick was made from aluminium sheet. The supporting frame was made out of rolled steel angles 40 mm x 40 mm x 5 mm. The trunnion assembly consisted of (1) a trunnion hub with bronze bushing, (2) a trunnion yoke and (3) a trunnion pin. Trunnion yoke was welded to

the gate chamber walls at a height 37.5 cm from the bottom surface of the conduit. The gate arms were connected to the trunnion pin. No slots were used and rubber seals were used to reduce the leakage of water through the sides of the gate from upstream side to downstream side.

The tainter gate having radius of 57.15 cm was provided with 18 piezometer tappings with c/c spacing 2 cm and with first piezomet r tapping from the bottom edge at a distance of 1 cm, while other model with radius 37.5 cm was provided with 18 piezometer tappings, c/c spacing 3 cm and with first tapping at a distance of 1 cm from bottom edge. One piezometer tapping was provided on the gate chamber to indicate the water level in the gate chamber and 18 on the bottom of the test section at 3 cm centres to locate the position of vena contracta of the jet. A piezometer tapping 2.5 cm upstream from the skin plate gave the approximate stagnation pressure. There were no piezometer tappings on the exit section. The location of piezometer tappings for tainter gates are shown in Figs. 3(b) and 3(c).

4.3 PROCEDURE AND ANALYSIS OF DATA

The following procedure was adopted in all the tests. By running the pump and opening the sluice valve in the supply line, water was let into the head tank. The piezometer tubes from the models were taken to a manometer board where the piezometric heads were indicated by piezometer tubes. The models were tested under submerged flow conditions at a number of gate openings. The required water level was maintained in the gate chamber by operating the downstream sluice valve. The piezometric heads were measured for various gate openings, gate chamber water levels, and jet Reynolds numbers. Before taking the readings all the air was removed from plastic connecting tubes.

The test procedure for the gates consisted of setting the gate to the desired position, allowing sufficient time of operation for conditions to stabilize, and than taking the readings. The model was then set to the next desired position and the procedure was repeated.

4.3.1 Downpull analysis for vertical lift gates:

Three series of experiments were performed with y/y_o ratio varying from 0.1 to 0.8. Reynolds numbers were varied from 0.3×10^5 to 4.14×10^5 and piezometer readings were noted for each gate opening. The measured

pressures are shown in tables 1, 2 and 3, respectively. The distribution of piezometric heads along the gate bottom was measured at nine points. The reference piezometric head h was obtained from a piezometer on the downstream side of the gate, 0.8 d above the lower edge. $V_J^2/2g$ was calculated from Eq. 4. Average pressure $\overline{K}_B$ was calculated by integrating piezometric head along the bottom Surface using Trapezoidal rule (Eq. 6). A piezometer (No. 6) on the roof centre line of the conduit 5.0 cm upstream from the gate was taken to calculate $\overline{K}_T$, as the water level in the gate chamber would be maximum if the leakage from the gate chamber to downstream side were totally stopped. Loss coefficient for **entrance** head loss (Eq. 1) was assumed as 0.5. The head at contracted jet was obtained from the piezometers on the downstream side of the gate.

The downpull force was calculated, using the data shown in Table 2. The sample calculations **for** a gate opening of .9 cm are shown below:

Height of conduit, y_o	=	30 cm
Width of conduit, B	=	30 cm
Gate thickness, d	=	7.62 cm
Gate opening, y	=	9.00 cm
Discharge, Q	=	38.10 **liters**/sec.
ν	=	$.07 \times 10^{-5}$ m^2/sec.

Piezometric head at the head tank, $H = 60.5$ cm

Piezometric head at the gate, $h_T = 59.5$ cm

Piezometric head at the vena contracta, $h_j = 46.0$ cm

Piezometric head of the reference tapping, $h = 46.3$ cm.

$$H_e = C_e \frac{1}{2g}\left(\frac{Q}{A}\right)^2 = 0.5 \times \frac{1}{2x9.81}\left(\frac{.0381}{.09}\right)^2 = .0046$$

$$V_J = \sqrt{2g\,(H - H_e - h_j)}$$

$$= \sqrt{2x9.81(60.5 - .0046 - 46.0)}$$

$$= 1.68 \text{ m/sec}$$

$$V_J^2/2g = 14.415 \text{ cm}$$

$$\bar{K}_T = \frac{1}{Bd}\int_0^d \int_0^B \frac{h_T - h}{V_J^2/2g}\, dB\, dx \approx \frac{h_T - h}{V_J^2/2g}$$

$$= (59 - 46.3)/14.415$$

$$= 0.9157$$

$$\bar{K}_B = \frac{1}{Bd}\int_0^d \int_0^B \frac{h_i - h}{V_J^2/2g}\, dB\, dx$$

The values of h_i, $\frac{h_i - h}{V_J^2/2g}$ are given in the following table from which

$$\bar{K}_B = 0.6254$$

Coefficient of downpull $(\bar{K}_T - \bar{K}_B) = 0.9157 - 0.6254$

$= 0.2903$

$$\text{Downpull} = (\bar{K}_T - \bar{K}_B)\ \frac{V_J^2}{2g}\ \gamma_w\ Bd$$

$$= \frac{0.2903 \times 14.415 \times 1 \times 30 \times 7.62}{} \times \frac{10^{-6} \times 10^3 \times 9.81}{9.81}\text{kgf}$$

$= 0.96$ Kgf.

$$\text{Reynolds Number } R = \frac{V_j\ d}{\nu} = \frac{1.68 \times 0.0762}{.07 \times 10^{-5}}$$

$$= 2.06 \times 10^5$$

i	1	2	3	4	5	6	7
h_i	59.00	57.70	56.25	57.00	57.50	56.70	56.00
$\frac{h_i - h}{V_J^2/2g}$	.8810	.7908	.6902	.7423	.7770	.7215	.6729

i	8	9	10
h_i	55.50	54.50	0.00
$\frac{h_i - h}{V_J^2/2g}$	.6382	.5688	0.00

4.3.2 Downpull analysis for tainter gates:

Series of experiments were performed to study the effect of different parameters on the downpull. To study the effect of Reynolds number on $\bar{K}$-values, Reynolds number was varied from 0.8×10^5 to 5.9×10^5 for the first model having radius of 57.15 cm and from 4.0×10^5 x 7.0×10^5 for the second model and piezometric heads were recorded for each gate opening. The observed pressures are shown in Tables 4, 5, 6, 7, 8, and 9.

Also experiments were conducted to study the effect of gate chamber water level on $\bar{K}$-values as well as on $(\bar{K}_T - \bar{K}_B)$ by varying y/y_o from 0.2 to 0.5 with increments of 0.1. The observed piezometric heads are shown in Tables 10 to 17. The Reynolds numbers were kept at 2×10^5 and 5.6×10^5 for the two models while studying the above effect.

The head losses H_e between reservoir and gate section are calculated by using Eq. 1. $V_J^2/2g$, which depends entirely on the flow pattern is calculated from Eq. 4. The values of $\bar{K}_B$ and $\bar{K}_T$ are calculated using Eqs. 6 and 7 respectively and downpull is obtained from Eq. 8. As an example calculations for the data shown in Table 9, corresponding to 6 cm gate opening are given below:

Height of conduit, y_o = 30 cm

Width of conduit, B = 30 cm

Gate thickness, d = 33.54 cm

Gate opening, y = 6 cm

Discharge, Q = 0.022 m^3/sec

Area of cross, section A = 900 cm^2

H = 64.5 cm

h = 53.4 cm

C_e = 0.5

h_T = 55.0 cm

Water temperature = $30^\circ C$.

ν = $.07 \times 10^{-5}$ m^2/sec.

$$H_e = C_e \frac{1}{2g} \left(\frac{Q}{A}\right)^2 = 0.152 \text{ cm.}$$

$$V_J = \sqrt{2g(H-H_e-h)} = 147.39 \text{ cm/sec.}$$

$$V_J^2/2g = 11.0718$$

$$\overline{K}_T = (h_T - h)/(V_J^2/2g) = 0.145$$

Values of $(h_i - h)/(V_J^2/2g)$ are shown in table below, from which

$$\overline{K}_B = \frac{1}{Bd} \int_0^d \int_0^B \frac{h_i - h}{V_J^2/2g} \, dB \, dx = 0.7455$$

$$\text{Downpull} = (\overline{K}_T - \overline{K}_B) \, B \, d \, \gamma_w \, V_J^2/2g$$

$$= (.145 - .7455) \times 30.0 \times 33.54 \times 1.0 \times 11.0718/1000$$

$$= -6.65 \text{ Kgf.}$$

Renolds No. $= V_J \times d/\nu \quad = 7.06 \times 10^5$

i	1	2	3	4	5	6	7	8
h_i	60.70	60.40	59.00	57.60	58.10	59.00	60.50	63.90
K_B	.6593	.6322	.5056	.3793	.4245	.5056	.6413	.9484

i	9	10	11	12	13	14	15	16
h_i	64.40	64.40	64.20	64.00	63.70	63.40	62.90	62.30
K_B	.9935	.9935	.9755	.9574	.9303	.9032	.8580	.8039

i	17	18	19
h_i	60.80	58.20	0.00
K_B	0.6684	.4335	0.00

CHAPTER V

DISCUSSION OF RESULTS

5.1 EFFECT OF y/y_o ON $\bar{K}$ VALUES

The graphs of y/y_o versus $\bar{K}_T$ are shown in Figs. 8(a), 8(b) and 8(c) for vertical lift gate, tainter gate with $r/y_o = 1.875$, and tainter gate with $r/y_o = 1.25$, respectively. For vertical lift gate and tainter gate with $r/y_o = 1.25$, $\bar{K}_T$ first increases upto $y/y_o = 0.3$ and then decreases with further increase in y/y_o. The general decrease of $\bar{K}_T$ is due to the fact that the stagnation piezometric head decreases with increase in relative gate opening.

In Figs. 9(a), 9(b) and 9(c) the effect of y/y_o on $\bar{K}_B$ has been shown by plotting y/y_o versus $\bar{K}_B$. From all these graphs it follows that $\bar{K}_B$ first decreases, reaches a minimum, again increases and then decreases. The results for vertical lift gate are in close agreement with the results of Naudascher (12).

The effect of y/y_o on $(\bar{K}_T - \bar{K}_B)$ is shown in Figs. 10(a), 10(b) and 10(c) for the three models. For vertical lift gate, $(\bar{K}_T - \bar{K}_B)$ is positive at all gate openings which indicates downpull force. $(\bar{K}_T - \bar{K}_B)$ first increases with the increase in y/y_o, reaches a maximum, and subsequently decreases with further increase in y/y_o. Maximum value occurs at 30 per cent gate opening.

For tainter gates, $(\overline{K}_T - \overline{K}_B)$ has been found to be negative at all gate openings and hence indicates uplift rather than downpull. $(\overline{K}_T - \overline{K}_B)$ decreases first as y/y_o increases and again increases after reaching a minimum value. The minimum value of $(\overline{K}_T - \overline{K}_B)$ for tainter gate with $r/y_o = 1.875$ is observed at about $y/y_o = 0.2$ while for tainter gate with $r/y_o = 1.25$, there are two minima for $(\overline{K}_T - \overline{K}_B)$ at $y/y_o = 0.2$ and 0.5. For all the gate models, $(\overline{K}_T - \overline{K}_B)$ tends to zero as y/y_o tends to zero and unity as required.

5.2 EFFECT OF h_G/y_o ON $\overline{K}$ VALUES

In Figs. 11(a) and 11(b), the effect of h_G/y_o on $\overline{K}_T$ is shown for tainter gates. It has been observed that $\overline{K}_T$ increases slowly as h_G/y_o increases. Figs. 12(a) and 12(b) show the effect of variation of h_G/y_o on $\overline{K}_B$. It is found that $\overline{K}_B$ decreases as h_G/y_o increases from 0.82 to 1.32. The rate of decrease of $\overline{K}_B$ with the increase in h_G/y_o is more in the case of tainter gate with $r/y_o = 1.25$ as compared to tainter gate with $r/y_o = 1.875$. The reason for this could be that as h_G/y_o increases, there is a tendency towards attaining hydrostatic pressure distribution.

$(\overline{K}_T - \overline{K}_B)$ is plotted against h_G/y_o in Figs. 13(a), and 13(b) for tainter gates with $r/y_o = 1.875$ and $r/y_o = 1.25$,

respectively. In both cases, in general, $(\overline{K}_T - \overline{K}_B)$ is found to increase towards a value of zero as h_G/y_o increases, because at lower water level in the gate chamber upward pressure is more as compared with downward pressure. But as the water level in the gate chamber increases downward pressure increases while upward pressure indicated by $\overline{K}_B$ decreases. This also shows tendency towards attaining hydrostatic pressure distribution as h_G/y_o increases.

5.3 EFFECT OF REYNOLDS NUMBER ON K-VALUES

When the flow departs from irrotational conditions, $\overline{K}_T$ and $\overline{K}_B$ depend upon the Reynolds number as well as on boundary geometry. Tests indicate, however, that relative distribution of piezometric head tends to become independent of the Reynolds number for higher values of Reynolds number. The effect on the distribution of piezometric head along the model surfaces are shown in Figs. 5, 6 and 7, for the three models, corresponding to maximum value of the parameter $(\overline{K}_T - \overline{K}_B)$. In all these figures $\overline{K}_B$ is shown against x/d ratio for different Reynolds numbers, where x is the horizontal distance of the piezometer tapping from upstream face [Fig.1(b)] and d is the thickness of the gate.

Since R is sufficiently high in practically all high-head installations, the $\overline{K}$-values should be uniquely

predictable for a given boundary form even in cases of local flow separation. It is evident from Figs. 5, 6 and 7, that Reynolds number still affects K_B at low values, but for higher values of Reynolds number K_B is not affected.

The effect of Reynolds number and other geometric parameters on downpull parameter $\overline{K}_T$ is shown in Figs. 8(a), 8(b) and 8(c) for the three models. In these figures $\overline{K}_T$ is plotted against y/y_o ratio for different Reynolds numbers. The other geometric parameters are also shown. It is evident from these figures that $\overline{K}_T$ increases with the increase in Reynolds number but is independent at higher values of Reynolds numbers.

In Figs. 9(a), 9(b) and 9(c), $\overline{K}_B$ is plotted against y/y_o ratio for different Reynolds number for the three models to study the effect of R and geometric parameters on downpull parameter $\overline{K}_B$. The influence of the various geometric parameters and Reynolds number on $(\overline{K}_T - \overline{K}_B)$ for the three models shown in Figs. 10(a), 10(b) and 10(c). The magnitude of $(\overline{K}_T - \overline{K}_B)$ is smaller at lower Reynolds number, while it increases as the Reynolds number increases thereby increasing the downpull. Observed pressure variation along the conduit and on the gate is also plotted for 3 cm tainter gate opening (Table 5) and is shown in Fig. 14.

CHAPTER - VI

CONCLUSIONS

The conclusions based on the experimental study are given below:

1. Downpull force is indicated on vertical lift gate at all gate openings while for tainter gates uplift forces are observed.

2. Effect of relative gate opening on $(\bar{K}_T - \bar{K}_B)$ for the three types of gates:
   For vertical lift gate $(\bar{K}_T - \bar{K}_B)$ increases as the relative gate opening increases. It reaches a maximum value at 30 per cent gate opening and then decreases with further increase in gate opening. For the tainter gate with $r/y_o = 1.875$, $(\bar{K}_T - \bar{K}_B)$ is negative and its magnitude decreases first, reaches a minimum at 20 per cent gate opening and then increases as y/y_o increases. For tainter gate with $r/y_o = 1.25$, the negative value of $(\bar{K}_T - \bar{K}_B)$ has two minima at 20 per cent and 50 per cent relative gate openings.

3. Effect of gate chamber water level on $(\bar{K}_T - \bar{K}_B)$ for tainter gates:
   The magnitude of $(\bar{K}_T - \bar{K}_B)$ has been found to increase with the increase in water level in the gate chamber, however, the rate of increase of $(\bar{K}_T - \bar{K}_B)$ is more

in the case of tainter gate with $r/y_o = 1.25$ as compared with tainter gate having $r/y_o = 1.875$.

4. Effect of Reynolds number on $(\overline{K}_T - \overline{K}_B)$ for the three types of gates:

   $(\overline{K}_T - \overline{K}_B)$ has been found to be independent of Reynolds number at high values of Reynolds number.

APPENDIX - I

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22. ISI Code on Liquid Flow Measurement in Open Channels Using Thin Plate Weirs.

TABLE 1: PIEZOMETER READINGS FOR VERTICAL LIFT GATE, IN CM.

REYNOLDS NO.= .3E+05

DISCHARGE (Cu.m/sec):	0.0181	0.0362	0.055	0.111	0.15	0.084
y/y_0:	0.1	0.2	0.3	0.4	0.6	0.8
PIEZOMETER NO.						
1	30.40	61.00	60.00	61.90	56.00	58.10
2	30.30	60.90	59.90	61.60	55.70	57.60
3	30.30	60.80	59.90	61.60	55.70	57.60
4	30.30	60.80	59.90	61.50	55.70	57.60
5	30.30	60.80	59.90	61.50	55.70	57.60
6	30.30	60.60	59.90	61.40	55.60	57.60
7	30.30	60.40	59.50	61.00	55.35	57.50
8	30.25	60.50	59.30	61.10	55.30	57.40
9	30.30	61.00	59.40	61.40	55.35	57.30
10	30.35	60.70	59.50	61.30	55.40	57.50
11	30.20	60.50	59.80	61.60	55.45	57.60
12	30.20	60.50	59.60	61.50	55.65	57.30
13	30.30	60.70	59.70	61.40	55.60	57.70
14	30.20	60.60	59.70	61.35	55.50	57.50
15	30.10	60.50	59.80	61.40	55.55	57.55
16	30.15	61.00	59.90	61.45	55.60	57.60
17	30.20	61.10	60.00	61.50	55.65	57.70
18	30.25	61.20	59.90	61.55	55.75	57.75
19	30.15	61.10	60.00	61.50	55.70	57.70
20	30.10	61.00	59.90	61.45	55.60	57.60
21	30.05	59.90	59.70	61.40	55.50	57.50
22	29.95	59.80	59.60	61.35	55.40	57.40
23	30.00	59.60	59.50	61.20	55.30	57.60
24	30.00	59.40	59.50	61.30	55.60	57.50
25	30.00	59.50	59.50	61.10	55.80	57.40
26	30.00	59.40	59.50	61.40	55.80	57.50
27	30.00	59.40	59.50	61.40	55.80	57.50
28	30.00	59.70	59.40	61.60	55.70	57.80
29	30.00	59.30	59.70	61.50	55.70	57.80
30	30.00	59.40	59.70	61.50	55.70	57.80
31	30.00	59.50	59.70	61.60	55.60	57.75
32	30.00	59.50	59.80	61.60	55.70	57.70
33	30.00	59.60	59.80	61.60	55.80	57.70
34	30.00	59.60	59.80	61.60	56.00	57.70
35	30.00	59.60	59.80	61.60	56.00	57.70

TABLE 2: PIEZOMETER READINGS FOR VERTICAL LIFT GATE, IN CM.

REYNOLDS NO.= .2E+06

DISCHARGE (Cu.m/sec):	0.0125	0.0254	0.0381	0.051	0.077	0.084	0.09
y/y_o:	0.1	0.2	0.3	0.4	0.6	0.7	0.8
PIEZOMETER NO.							
1	42.00	54.50	60.50	56.00	54.00	49.50	62.00
2	41.00	53.70	59.50	54.00	48.00	42.50	53.00
3	41.70	53.70	59.50	54.00	49.00	43.30	53.00
4	41.60	53.70	59.50	54.00	48.00	42.10	52.30
5	41.60	53.70	59.50	54.00	49.00	42.30	53.00
6	41.60	53.70	59.50	54.00	49.20	44.00	53.50
7	32.60	41.80	46.30	38.75	36.00	34.00	48.00
8	32.70	42.00	46.20	39.00	36.25	35.00	48.00
9	41.30	42.10	46.10	39.25	36.50	35.00	48.00
10	41.90	54.30	45.90	39.50	36.00	34.50	48.00
11	41.80	54.20	59.50	55.25	35.75	34.00	48.50
12	41.70	54.00	59.40	55.50	48.25	35.50	46.50
13	41.60	53.50	59.00	54.25	49.75	45.00	51.00
14	41.10	52.70	57.70	53.25	49.00	45.50	52.00
15	40.80	51.60	56.25	50.75	47.25	46.00	55.50
16	41.20	52.00	57.00	51.50	47.50	46.50	58.00
17	41.30	52.20	57.50	51.75	46.25	44.00	59.50
18	41.10	51.80	56.70	51.25	45.50	43.70	57.00
19	41.00	51.40	56.00	50.25	45.00	43.00	56.00
20	40.40	50.60	55.50	49.00	43.75	41.50	54.25
21	39.30	49.10	54.50	47.50	42.00	39.80	52.50
22	31.80	40.60	46.30	40.00	35.00	32.50	44.00
23	32.10	40.80	46.50	38.50	35.00	33.00	47.00
24	31.80	40.60	46.50	38.75	35.50	34.50	45.50
25	32.20	40.60	46.75	39.00	35.75	34.70	48.00
26	31.80	41.20	47.00	39.00	36.00	35.00	48.10
27	32.80	41.50	46.50	39.00	36.00	35.20	48.20
28	31.90	40.50	46.25	38.00	39.25	33.00	44.80
29	31.70	40.50	50.00	39.00	39.00	32.90	44.70
30	31.90	41.20	53.00	45.25	42.00	32.80	44.65
31	34.10	47.20	47.50	43.00	41.00	32.80	44.65
32	31.80	45.40	46.00	40.00	35.00	32.60	44.50
33	32.00	46.80	47.50	41.75	40.50	32.70	44.60
34	31.80	48.00	48.00	40.00	41.00	32.70	44.60
35	35.00	45.50	50.00	39.00	35.00	32.70	44.70

TABLE 3: PIEZOMETER READINGS FOR VERTICAL LIFT GATE, IN CM.

DISCHARGE (Cu.m/sec):	0.12E-01	0.12E-01	0.13E-01	0.87E-01	0.10E+00	0.11E+00
REYNOLDS NO.	0.41E+06	0.41E+06	0.33E+06	0.35E+06	0.30E+06	0.17E+06
y/y_o :	0.1	0.20	0.3	0.4	0.6	0.8
PIEZOMETER NO.						
1	83.00	79.00	75.00	79.50	70.00	70.00
2	82.00	75.80	70.50	73.00	57.50	57.50
3	82.20	75.80	70.50	73.20	57.40	57.40
4	82.20	75.80	70.50	73.30	57.20	57.20
5	82.20	75.80	70.60	73.50	58.00	58.00
6	82.30	76.00	71.00	75.50	59.80	58.50
7	43.00	21.50	39.30	28.00	32.00	34.00
8	19.00	14.25	30.50	28.00	31.80	52.25
9	81.00	14.30	30.40	28.50	31.75	52.00
10	81.10	77.50	31.00	28.60	31.70	51.75
11	81.00	77.70	71.00	76.50	31.20	51.00
12	80.00	76.90	71.20	77.70	61.00	49.00
13	79.00	72.50	69.50	75.20	62.00	55.00
14	76.00	68.20	64.30	71.50	60.25	55.80
15	74.00	63.00	59.00	64.00	57.50	64.00
16	83.00	63.80	59.90	65.00	56.50	61.50
17	82.00	67.50	61.90	66.00	56.30	62.00
18	82.20	64.00	60.50	65.10	56.50	60.00
19	82.20	61.50	58.50	63.00	53.00	59.00
20	82.20	56.00	55.50	59.00	49.50	57.50
21	82.30	49.00	50.00	54.00	45.00	55.00
22	43.00	6.50	26.00	28.00	30.00	47.00
23	19.00	6.50	26.00	27.80	29.75	50.75
24	81.00	6.60	26.00	27.80	30.50	52.00
25	81.10	6.50	26.00	30.00	31.00	52.50
26	81.00	8.50	28.50	30.50	31.20	53.00
27	80.00	13.00	29.30	30.70	31.30	53.20
28	79.00	6.10	28.00	28.00	30.30	47.00
29	76.00	6.00	29.50	27.90	30.20	47.50
30	74.00	6.20	29.20	27.85	30.00	47.20
31	9.20	6.20	27.50	27.80	30.10	46.00
32	9.20	6.20	30.00	27.90	30.20	46.10
33	9.20	6.20	28.00	27.85	30.25	46.20
34	9.20	6.20	27.70	27.85	30.30	46.10
35	9.30	6.20	27.70	27.85	30.30	46.10

TABLE 4: PIEZOMETER READINGS FOR TAINTER GATE, IN CM.

REYNOLDS NO.= .8E+05, r/y_0 =1.875

DISCHARGE (Cu.m/sec):	0.005	0.007	0.01	0.015	0.017	0.024	0.032
y/y_0 :	0.1	0.2	0.3	0.4	0.5	0.6	0.7
PIEZOMETER NO.							
1	55.80	56.50	56.20	56.00	56.50	56.50	57.00
2	55.70	56.30	56.00	55.80	56.20	56.20	56.30
3	55.70	56.30	56.00	56.00	56.20	56.20	56.30
4	55.70	56.40	56.00	55.80	56.20	56.20	56.30
5	55.70	56.30	56.05	55.80	56.30	56.25	56.50
6	54.80	55.30	55.10	54.85	55.25	55.25	55.50
7	55.40	55.50	54.70	54.80	55.90	54.80	56.40
8	55.50	55.60	54.80	54.00	55.70	54.75	56.50
9	55.60	55.80	55.00	54.10	55.60	54.70	56.60
10	55.70	56.20	55.20	54.40	55.50	54.85	56.70
11	55.70	56.25	55.40	54.60	55.30	54.90	56.70
12	55.70	56.30	55.80	54.60	55.80	54.95	56.70
13	55.70	56.30	56.10	55.60	55.80	55.00	56.50
14	55.70	56.30	56.10	55.80	56.20	55.05	56.80
15	55.70	56.30	56.10	55.80	56.30	55.10	56.80
16	55.70	56.30	56.10	55.80	56.30	55.20	56.80
17	55.70	56.40	56.10	55.80	56.30	55.30	56.80
18	55.70	56.30	56.10	55.80	56.30	55.40	56.80
19	55.70	56.25	56.00	55.70	56.30	55.45	56.90
20	55.70	56.25	55.95	55.60	56.30	55.50	56.90
21	55.70	56.20	55.90	55.60	56.20	55.30	56.90
22	55.50	56.20	55.80	55.50	56.00	55.20	56.85
23	55.10	55.90	55.40	55.10	55.40	54.95	56.80
24	54.70	55.50	55.20	54.80	54.70	54.90	56.30
25	55.70	56.20	55.90	55.50	55.80	54.90	54.80
26	55.60	56.10	55.70	55.30	55.40	55.50	56.50
27	55.50	56.00	55.40	55.00	55.00	55.30	56.00
28	55.20	55.80	55.20	54.70	55.10	55.10	55.60
29	54.60	55.70	55.00	54.70	55.20	55.30	55.50
30	54.50	55.20	55.10	54.60	55.30	55.10	55.60
31	54.50	55.20	55.20	54.70	55.30	55.50	55.50
32	54.40	54.90	54.80	54.50	55.20	55.20	55.70
33	54.50	55.10	54.90	54.60	55.20	55.30	55.70
34	54.50	55.00	55.00	54.50	55.30	55.30	55.50
35	54.50	55.00	55.00	54.70	55.30	55.40	55.70
36	54.60	55.10	55.10	54.80	55.20	56.00	55.60
37	54.50	55.00	54.90	54.90	55.30	55.00	55.70
38	54.50	55.10	55.00	55.00	55.30	55.30	55.80
39	54.50	55.00	55.90	54.40	55.00	55.10	55.40
40	54.50	55.00	55.90	54.90	55.30	55.00	55.80
41	54.50	55.00	55.85	54.90	55.30	54.80	55.90
42	54.50	55.00	55.90	54.90	55.25	55.40	55.80
43	54.50	55.00	56.00	54.90	55.30	55.30	55.70

TABLE 5: PIEZOMETER READINGS FOR TAINTER GATE, IN CM.

REYNOLDS NO.= .16E+06, r/y_0 =1.875

DISCHARGE (Cu.m/sec):	0.01	0.011	0.02	0.026	0.03	0.035	0.04
y/y_0:	0.1	0.2	0.3	0.4	0.5	0.6	0.7
PIEZOMETER NO.							
1	61.10	60.20	60.30	60.30	59.50	60.30	60.00
2	60.90	60.00	59.90	59.50	58.50	59.00	58.00
3	60.85	60.00	59.90	59.50	58.60	59.00	58.50
4	60.90	60.10	60.00	59.50	58.90	59.10	58.60
5	61.00	60.10	60.00	59.70	59.00	59.50	58.70
6	59.00	58.10	58.00	57.10	56.50	57.50	54.80
7	59.60	58.10	56.70	52.20	55.80	59.20	59.70
8	60.20	58.70	56.70	52.30	55.10	59.10	59.60
9	60.90	58.80	56.70	53.20	54.70	58.75	59.50
10	60.90	59.80	56.80	54.40	54.60	58.60	59.40
11	60.90	60.00	58.00	54.10	53.70	58.20	59.30
12	60.95	60.10	59.50	54.60	54.10	57.60	59.10
13	61.00	60.10	59.70	58.50	55.90	58.40	59.20
14	60.95	60.10	59.80	60.00	58.50	58.70	59.25
15	60.95	60.05	59.90	60.05	56.50	58.75	59.30
16	60.95	60.00	60.00	60.10	59.10	59.20	59.30
17	60.95	60.00	59.90	60.00	59.20	60.00	59.30
18	60.90	59.95	59.80	59.90	59.10	60.10	59.35
19	60.80	59.80	59.70	59.70	58.90	60.00	59.40
20	60.70	59.70	59.60	59.60	58.70	59.80	59.45
21	60.60	59.60	59.50	59.20	58.50	59.60	59.50
22	60.50	59.40	59.30	58.90	58.30	59.50	59.00
23	60.10	59.00	58.80	58.40	57.70	58.00	58.50
24	57.40	55.80	57.50	57.00	55.70	56.00	57.20
25	60.90	60.50	60.00	59.50	58.70	59.00	58.50
26	60.80	60.00	59.50	58.50	57.50	58.50	57.30
27	60.60	59.10	57.50	57.00	57.70	57.00	56.20
28	59.80	58.00	56.50	56.20	56.20	56.60	56.00
29	58.40	57.00	55.50	55.70	56.00	56.60	56.00
30	56.70	55.00	54.50	55.00	55.50	55.70	55.80
31	57.10	56.50	55.20	55.50	55.40	56.20	56.40
32	55.80	55.00	55.00	55.90	55.50	56.50	56.30
33	55.30	54.60	54.70	54.70	54.40	55.00	55.00
34	56.40	55.80	55.50	55.70	54.70	55.50	56.00
35	56.00	55.30	55.00	55.30	54.60	55.30	56.50
36	55.80	55.10	55.10	55.10	54.50	55.00	56.30
37	56.70	55.50	55.80	55.50	54.80	55.50	56.10
38	56.90	55.70	56.00	55.60	54.90	55.60	56.20
39	55.80	54.70	54.80	54.60	54.00	54.60	54.50
40	56.80	56.00	56.40	55.50	54.90	55.80	56.20
41	56.20	55.50	56.00	55.00	54.50	55.70	56.00
42	56.30	55.50	55.90	55.00	54.30	55.50	55.70
43	56.60	56.00	56.50	55.60	54.50	56.00	56.30

TABLE 6: PIEZOMETER READINGS FOR TAINTER GATE, IN CM.
r/y =1.875

DISCHARGE (Cu.m/sec):	0.30E-01	0.42E-01	0.50E-01	0.59E-01	0.50E-01	0.69E-01	0.69E-01	0.65E-01
REYNOLDS NO.	0.59E+06	0.56E+06	0.48E+06	0.43E+06	0.39E+06	0.30E+06	0.27E+06	0.25E+06
y/y_0 :	0.1	0.20	0.3	0.4	0.5	0.6	0.7	0.8
PIEZOMETER NO.								
1	82.00	81.50	80.30	83.20	67.50	77.50	74.00	75.50
2	80.80	79.30	79.20	79.50	65.00	74.50	69.70	71.50
3	80.90	79.50	79.30	79.60	65.20	74.60	69.80	71.60
4	81.00	79.50	79.30	79.70	65.30	74.60	69.80	71.60
5	81.30	80.00	79.30	81.00	65.50	75.60	70.40	72.60
6	54.80	54.80	54.80	54.80	54.80	54.80	54.80	54.80
7	72.80	68.00	54.50	30.00	52.60	53.50	60.00	60.50
8	80.50	69.80	61.00	44.60	51.40	47.50	56.00	58.90
9	81.60	77.80	64.30	52.00	50.00	44.20	53.00	58.20
10	81.80	80.80	68.50	58.60	50.50	45.00	51.30	57.50
11	81.70	81.20	78.90	81.30	47.50	48.50	51.20	52.50
12	81.65	81.10	79.30	81.50	49.00	53.50	53.80	53.30
13	81.60	81.00	80.10	81.70	54.50	57.50	56.00	54.10
14	81.40	80.80	80.00	82.20	55.50	60.50	58.80	56.50
15	81.30	80.60	79.90	82.40	58.00	72.50	59.50	57.80
16	81.20	80.20	79.70	82.00	67.20	76.10	67.20	59.00
17	80.95	79.80	79.50	81.50	67.30	76.80	72.00	64.50
18	80.70	79.40	79.00	81.00	67.30	77.00	72.50	72.00
19	80.20	78.40	78.10	80.00	66.80	76.30	72.40	73.10
20	79.70	77.50	77.20	79.00	66.40	75.70	72.30	74.20
21	79.00	76.30	76.00	77.80	65.00	75.00	71.80	73.80
22	78.00	74.50	76.00	76.00	65.20	73.90	71.00	73.00
23	74.70	69.60	70.10	72.50	63.50	71.50	69.50	72.00
24	51.70	63.00	56.50	54.50	59.00	58.20	59.00	63.60
25	81.00	77.20	74.50	77.00	64.50	71.00	68.00	69.00
26	80.50	76.80	74.10	73.00	61.50	60.00	65.40	67.00
27	79.00	71.60	66.00	64.00	58.00	53.00	62.00	64.50
28	75.80	63.20	56.50	51.00	58.30	61.00	60.50	64.00
29	67.00	47.00	46.50	52.50	57.20	60.70	60.60	64.40
30	15.00	15.00	32.00	45.00	55.00	57.00	59.00	62.50
31	14.00	22.50	38.50	49.50	55.00	60.00	60.50	64.00
32	4.50	11.50	29.00	45.50	55.10	58.00	59.50	63.00
33	11.30	16.00	29.50	43.60	54.50	57.50	59.00	62.80
34	14.00	21.00	35.50	45.50	55.50	58.50	59.60	63.20
35	10.50	16.50	32.00	44.00	54.30	57.00	58.60	61.50
36	9.50	13.50	30.00	41.50	54.50	55.50	57.00	61.00
37	14.50	14.30	34.00	42.00	54.60	56.20	58.10	62.00
38	13.20	13.90	33.50	42.10	54.70	56.40	58.20	62.20
39	14.60	13.70	33.20	42.00	52.40	55.30	57.00	61.00
40	14.90	13.80	33.40	40.20	55.20	55.40	57.10	61.50
41	13.10	14.20	33.60	40.30	54.20	56.00	57.30	61.60
42	15.30	14.00	33.50	40.50	54.10	56.10	57.00	61.10
43	15.50	14.20	33.50	41.00	56.50	56.20	57.50	63.00

TABLE 7: PIEZOMETER READINGS FOR TAINTER GATE, IN CM.

REYNOLDS NO.= .4E+06, r/y_0 =1.25

DISCHARGE (Cu.m/sec):	0.80E-02	0.10E-01	0.12E-01	0.20E-01	0.25E-01	0.27E-01	0.33E
y/y_0 :	0.1	0.2	0.3	0.4	0.5	0.6	0.7
PIEZOMETER NO.							
1	57.20	58.30	57.10	56.50	58.60	58.50	73.00
2	57.10	58.10	56.80	56.00	57.80	57.50	71.80
3	57.10	58.10	56.80	56.10	57.90	57.70	71.80
4	57.10	58.10	56.80	56.10	57.90	57.70	71.90
5	57.10	58.10	56.85	56.20	58.10	57.80	72.00
6	54.50	55.50	54.80	55.00	55.50	55.50	70.00
7	55.60	58.20	57.00	56.20	58.20	58.00	72.50
8	55.20	58.20	57.00	56.20	58.20	58.00	72.50
9	55.10	58.10	57.00	56.20	58.20	58.00	72.50
10	55.60	58.10	56.90	56.20	58.20	58.00	72.50
11	55.80	58.10	56.90	56.20	58.20	58.00	72.50
12	56.80	58.00	56.80	56.00	58.00	58.00	72.30
13	57.10	58.20	57.00	56.20	58.20	58.00	72.50
14	57.10	58.20	57.00	56.20	58.20	58.00	72.50
15	57.10	58.20	57.00	56.20	58.20	58.00	72.50
16	57.10	58.20	57.00	56.20	58.20	58.00	72.50
17	57.10	58.20	57.00	56.20	58.20	58.00	72.50
18	57.10	58.20	57.00	56.20	58.20	58.00	72.50
19	57.00	58.10	57.00	56.20	58.30	58.00	72.20
20	56.90	58.00	56.90	56.10	58.40	58.10	72.40
21	56.80	57.90	56.80	55.90	58.30	58.40	72.50
22	56.70	57.80	56.70	55.70	58.10	58.30	72.80
23	56.20	57.20	55.30	55.20	57.60	57.70	72.20
24	55.40	56.50	54.40	54.20	56.60	56.70	71.50
25	57.10	58.20	57.00	56.00	58.00	57.40	72.00
26	57.00	58.10	56.80	55.70	58.60	57.20	71.60
27	57.00	58.00	56.70	55.40	58.20	56.60	71.40
28	56.80	57.90	56.20	54.80	57.80	56.40	71.20
29	56.80	57.70	56.10	54.80	57.90	56.40	71.00
30	56.70	57.20	55.00	54.60	56.50	56.00	70.60
31	56.40	56.80	55.40	54.50	56.20	56.00	70.70
32	55.80	56.50	55.20	54.20	56.20	55.90	70.60
33	54.50	55.80	54.50	53.20	55.70	55.70	70.20
34	55.10	56.30	55.20	53.80	56.50	55.90	70.50
35	54.60	56.00	54.80	53.50	56.30	55.70	70.20
36	54.30	55.80	54.60	53.40	56.10	55.50	70.00
37	54.70	56.00	55.00	54.50	56.20	55.70	70.50
38	54.10	55.50	54.40	54.00	55.60	55.40	70.00
39	53.80	54.80	53.60	52.90	55.00	55.00	69.50
40	54.00	55.50	54.40	54.00	55.60	55.40	70.00
41	53.70	55.00	54.00	53.70	55.20	55.00	69.70
42	53.60	55.10	54.10	53.80	55.40	55.30	69.80
43	53.80	55.40	54.30	54.10	55.60	55.40	70.00

TABLE 8: PIEZOMETER READINGS FOR TAINTER GATE, IN CM.

REYNOLDS NO. = .58E+06, r/y_0 = 1.25

DISCHARGE (Cu.m/sec):	0.018	0.019	0.022	0.029	0.035	0.043	0.049
y/y_0 :	0.1	0.2	0.3	0.4	0.5	0.6	0.7
PIEZOMETER NO.							
1	60.70	61.50	60.50	60.50	63.00	61.50	76.00
2	60.40	61.20	59.90	59.60	61.90	59.70	73.60
3	60.40	61.20	59.90	59.60	62.00	59.80	73.70
4	60.40	61.20	60.00	59.70	62.10	59.80	73.90
5	60.50	61.25	60.10	59.80	62.20	60.00	74.10
6	54.80	55.00	54.80	55.00	56.00	55.20	70.00
7	54.60	60.50	60.20	60.20	62.00	60.60	74.50
8	53.00	60.40	60.20	60.20	62.00	60.60	74.50
9	53.70	60.00	60.20	60.20	62.00	60.60	74.50
10	54.40	59.70	60.20	60.20	62.00	60.60	74.50
11	55.50	59.80	60.20	60.20	62.00	60.60	74.50
12	54.60	59.90	60.00	60.00	61.80	60.40	74.40
13	60.50	60.00	60.20	60.20	62.00	60.50	74.50
14	60.60	60.60	60.20	60.20	62.00	60.50	74.50
15	60.60	61.30	60.20	60.25	62.00	60.50	74.50
16	60.50	61.40	60.20	60.30	62.00	60.40	74.50
17	60.50	61.40	60.30	60.30	62.00	60.40	74.40
18	60.50	61.40	60.30	60.30	62.10	60.40	74.10
19	60.30	61.20	60.10	60.30	62.30	60.40	74.20
20	60.20	60.90	59.90	59.80	62.50	60.70	74.60
21	59.90	60.60	59.50	59.40	62.10	61.10	75.00
22	59.80	60.30	59.00	58.90	61.70	60.90	75.50
23	58.60	59.50	58.20	57.90	60.70	59.70	75.10
24	56.90	57.70	56.20	55.70	58.30	57.30	73.10
25	60.40	61.30	60.30	60.00	61.00	59.00	73.20
26	60.30	61.10	60.20	59.50	60.50	58.60	72.50
27	60.20	61.00	60.00	57.80	59.00	57.50	71.60
28	60.00	59.90	59.00	57.20	58.50	57.30	71.20
29	59.90	59.60	58.70	57.00	58.50	57.30	71.50
30	59.40	58.50	57.00	56.20	58.00	56.60	71.50
31	58.60	57.50	56.40	56.00	58.00	56.50	71.60
32	57.10	56.50	56.00	55.70	58.00	56.70	71.50
33	54.20	55.00	55.00	55.00	56.80	55.00	69.80
34	55.30	56.40	56.20	56.20	58.00	56.30	71.00
35	54.70	55.60	55.20	55.70	57.50	56.00	70.50
36	53.80	55.10	54.20	55.10	57.00	55.50	69.90
37	55.00	55.80	55.50	56.20	57.50	56.60	71.00
38	53.80	54.50	54.20	55.00	56.50	55.00	69.80
39	53.20	54.00	52.80	53.00	55.50	54.00	69.00
40	53.80	54.60	54.40	55.00	56.50	55.00	69.00
41	53.40	54.30	54.00	54.20	56.00	54.50	69.50
42	53.40	54.30	54.10	54.30	56.20	55.00	69.60
43	54.00	55.00	54.50	54.80	56.50	55.70	70.20

TABLE 9: PIEZOMETER READINGS FOR TAINTER GATE, IN CM.

REYNOLDS NO.= .7E+06, r/y_0=1.25

DISCHARGE (Cu.m/sec):	0.018	0.022	0.029	0.035	0.043	0.051	0.061
y/y_0:	0.1	0.2	0.3	0.4	0.5	0.6	0.7
PIEZOMETER NO.							
1	65.50	64.50	63.50	64.50	65.00	66.00	76.00
2	65.00	64.00	62.70	63.30	63.00	63.50	72.30
3	65.00	64.00	62.70	63.30	63.10	63.60	72.40
4	65.00	64.00	62.80	63.30	63.30	63.70	72.40
5	65.10	64.10	62.90	63.50	63.50	64.00	73.20
6	55.20	55.00	55.50	55.00	55.00	56.20	67.00
7	53.50	60.70	62.90	63.70	63.60	64.40	74.00
8	50.30	60.40	62.90	63.70	63.60	64.40	74.00
9	49.50	59.00	62.80	63.60	63.60	64.30	74.00
10	53.00	57.60	62.80	63.60	63.60	64.30	74.00
11	55.50	58.10	62.80	63.60	63.60	64.30	74.00
12	63.60	59.00	62.60	63.50	63.40	64.10	74.00
13	65.20	60.50	63.00	63.50	63.60	64.30	74.00
14	65.30	63.90	63.00	63.50	63.50	64.20	74.00
15	65.40	64.40	63.10	63.50	63.40	64.00	74.00
16	65.40	64.40	63.20	63.50	63.40	64.00	74.00
17	65.30	64.20	63.30	63.70	63.40	64.00	73.60
18	65.20	64.00	63.30	64.20	63.70	64.00	73.60
19	64.90	63.70	62.90	64.20	64.20	64.90	73.50
20	64.70	63.40	62.40	63.70	64.50	64.90	73.50
21	64.40	62.90	62.00	63.20	63.90	65.50	74.30
22	63.90	62.30	61.50	62.50	63.30	65.00	75.00
23	62.50	60.80	60.10	61.00	61.80	63.50	74.20
24	59.20	58.20	56.70	57.80	58.80	60.20	70.80
25	65.10	64.00	62.60	62.00	63.50	62.00	71.00
26	65.00	63.80	62.00	61.50	62.50	61.00	70.40
27	64.70	62.30	61.20	60.50	61.00	59.00	68.70
28	64.30	61.80	59.50	59.70	60.00	58.50	68.50
29	64.10	60.20	59.00	59.20	60.00	58.50	68.50
30	63.30	59.00	57.50	57.50	59.50	58.00	68.40
31	62.00	57.50	57.00	57.20	59.50	58.00	68.30
32	59.00	57.00	56.00	56.80	59.00	57.90	68.20
33	54.50	55.50	54.50	56.00	57.50	56.50	67.80
34	56.00	57.50	56.20	57.80	59.50	58.00	69.00
35	54.90	56.50	55.00	56.50	58.00	57.00	68.20
36	53.50	55.00	54.30	55.80	57.50	56.00	67.20
37	56.50	57.50	56.10	56.50	58.50	57.50	69.00
38	54.50	56.00	53.50	55.00	57.00	55.50	67.20
39	53.00	53.40	52.50	53.00	54.00	54.00	65.00
40	54.70	56.00	53.70	55.10	57.20	56.30	67.40
41	54.00	54.50	53.00	54.20	57.00	55.00	67.00
42	54.10	54.60	53.20	54.30	57.30	55.30	67.50
43	55.00	55.00	54.00	55.50	58.00	56.30	68.20

TABLE 10: PIEZOMETER READINGS FOR TAINTER GATE, IN CM.

REYNOLDS NO.= 0.2E+06, Y/Y_0 = .20

h_G/Y_0 : PIEZOMETER NO.	1.32	1.13	0.98	0.82
1	77.00	71.00	66.00	61.70
2	76.70	70.70	65.60	61.20
3	76.80	70.70	65.60	61.30
4	76.80	70.70	65.70	61.30
5	76.90	70.80	65.75	61.40
6	69.90	64.00	59.00	54.80
7	73.20	67.40	62.40	58.00
8	74.10	68.30	63.30	58.90
9	74.40	68.50	63.50	59.20
10	76.20	70.10	65.50	61.20
11	76.50	70.60	65.60	61.40
12	76.50	70.70	65.65	61.50
13	76.70	70.80	65.70	61.60
14	76.80	70.80	65.80	61.60
15	76.80	70.80	65.80	61.60
16	76.80	70.60	65.80	61.60
17	76.70	70.55	65.80	61.50
18	76.50	70.50	65.70	61.45
19	76.40	70.45	65.65	61.40
20	76.40	70.40	65.60	61.35
21	76.10	70.30	65.40	61.30
22	75.10	70.10	65.20	61.10
23	75.20	69.40	65.50	60.60
24	72.10	66.60	62.00	57.50
25	76.30	71.00	65.50	61.40
26	75.80	70.50	65.40	61.00
27	75.00	69.50	65.20	60.20
28	74.20	68.80	65.30	59.80
29	71.60	66.20	60.80	56.40
30	69.00	63.80	58.50	54.50
31	69.50	63.90	58.40	54.60
32	69.60	64.00	59.30	54.70
33	68.40	64.10	57.40	53.40
34	69.20	62.70	58.20	54.50
35	69.40	64.30	59.20	54.50
36	69.10	64.50	58.10	54.30
37	69.30	64.70	58.30	54.40
38	69.50	64.80	58.40	54.60
39	68.20	62.40	57.20	53.00
40	69.60	65.00	58.60	54.00
41	68.70	64.50	57.80	54.10
42	68.60	64.30	57.90	54.70
43	69.60	65.50	58.50	55.00

TABLE 11: PIEZOMETER READINGS FOR TAINTER GATE, IN CM.

REYNOLDS NO. = 0.2E+06, Y/Y_0 = .30

h_G/Y_0 : PIEZOMETER NO.	1.32	1.13	0.98	0.82
1	76.50	71.50	66.00	62.00
2	64.80	69.80	65.40	61.00
3	65.00	69.90	65.50	61.10
4	65.20	69.90	65.50	61.20
5	76.10	71.00	65.60	61.60
6	69.30	64.00	59.00	54.80
7	68.10	62.80	57.50	53.50
8	71.20	64.50	59.60	55.40
9	71.60	65.70	60.80	57.00
10	72.00	67.00	61.40	57.50
11	72.80	67.40	65.00	58.30
12	74.80	70.40	65.30	61.10
13	76.20	71.10	65.70	61.70
14	76.30	71.20	65.80	61.80
15	76.30	71.20	65.80	61.75
16	76.30	71.20	65.70	61.70
17	76.30	71.10	65.65	61.60
18	76.20	71.00	65.60	61.50
19	76.10	70.80	65.50	61.40
20	75.90	70.60	65.40	61.30
21	75.70	70.40	65.30	61.10
22	75.30	70.10	65.10	60.80
23	74.60	69.40	64.40	59.80
24	71.80	66.50	61.40	57.00
25	76.00	71.20	65.80	61.50
26	74.80	70.00	64.70	60.40
27	74.00	69.00	63.80	59.20
28	73.50	67.80	62.80	58.40
29	71.50	66.00	60.60	54.50
30	69.80	64.00	59.00	54.60
31	69.90	64.20	59.10	54.70
32	70.00	64.30	59.20	54.80
33	68.50	73.00	57.80	53.80
34	70.10	73.40	58.80	54.80
35	70.30	73.50	58.90	54.50
36	70.00	73.20	58.70	54.20
37	70.20	73.40	58.80	54.30
38	70.40	73.60	58.90	54.40
39	67.50	62.00	57.10	53.00
40	70.60	73.80	59.00	54.10
41	69.80	73.20	58.30	54.50
42	69.70	73.40	58.50	55.00
43	70.50	74.00	58.80	55.50

TABLE 12: PIEZOMETER READINGS FOR TAINTER GATE, IN CM.

REYNOLDS NO.= 0.2E+06, Y/Y_0= .40

h_G/Y_0: / PIEZOMETER NO.	1.32	1.13	0.98	0.82
1	75.50	70.50	67.00	61.60
2	74.80	69.70	66.30	60.70
3	74.80	69.70	66.30	60.70
4	74.80	69.80	66.40	60.80
5	74.90	69.80	66.40	60.90
6	69.20	64.00	59.50	54.80
7	64.40	59.00	55.80	51.00
8	64.80	59.40	56.30	51.40
9	66.50	61.00	57.80	53.00
10	68.30	62.90	68.10	55.50
11	68.80	63.10	68.30	55.60
12	69.00	63.20	68.40	55.70
13	74.80	68.80	65.00	60.40
14	75.30	70.10	66.10	61.20
15	75.40	70.40	66.40	61.40
16	75.30	70.40	66.40	61.40
17	75.30	70.40	66.30	61.40
18	75.20	70.30	66.10	61.30
19	75.00	70.10	65.90	61.20
20	74.80	69.80	65.60	61.00
21	74.60	69.60	65.30	60.90
22	74.30	69.30	64.60	60.80
23	73.60	68.30	61.00	60.00
24	70.20	65.10	66.00	55.90
25	74.80	69.30	64.50	61.20
26	73.80	68.10	63.50	59.50
27	72.00	67.50	61.50	57.20
28	70.50	65.70	61.00	56.50
29	70.00	65.30	60.50	55.50
30	69.50	64.50	60.60	55.40
31	69.60	64.60	59.50	54.50
32	69.50	63.00	60.00	54.00
33	68.50	62.50	60.50	55.00
34	69.00	63.00	60.70	55.20
35	69.20	63.10	60.60	55.00
36	69.30	63.10	62.50	56.80
37	70.50	65.50	61.50	56.80
38	69.60	64.30	61.60	56.00
39	67.50	62.10	58.50	53.20
40	70.00	64.40	60.50	56.20
41	69.00	63.70	60.60	55.00
42	69.60	63.80	61.00	55.30
43	70.00	70.20	61.50	56.30

TABLE 13: PIEZOMETER READINGS FOR TAINTER GATE, IN CM.

REYNOLDS NO. = 0.2E+06, Y/Y_0 = .50

h_G/Y_0 : PIEZOMETER NO.	1.32	1.13	0.98	0.82
1	76.50	70.50	66.00	61.50
2	75.00	69.00	64.00	60.00
3	74.50	69.20	64.20	60.20
4	75.30	69.30	64.40	60.30
5	76.20	69.50	65.50	60.50
6	69.50	64.50	59.50	54.80
7	69.20	61.00	57.40	55.70
8	65.40	60.70	56.20	54.60
9	64.50	59.50	55.20	53.60
10	64.40	59.80	55.10	53.30
11	61.80	56.00	52.30	51.50
12	63.40	57.00	54.20	52.80
13	67.20	62.00	58.00	55.70
14	70.00	64.50	60.00	57.00
15	73.60	63.50	63.50	60.00
16	75.00	70.00	65.50	61.00
17	76.00	70.10	65.90	61.00
18	76.00	70.10	65.90	61.00
19	75.90	70.10	65.80	60.90
20	75.70	69.80	65.60	60.70
21	75.50	69.60	65.40	60.50
22	75.20	69.40	65.10	60.10
23	74.20	68.70	64.10	59.10
24	72.00	66.10	61.50	57.00
25	74.70	69.50	64.50	60.50
26	72.80	68.10	63.00	58.50
27	72.50	68.00	62.70	58.30
28	71.00	66.50	62.00	57.20
29	70.80	66.00	60.50	56.50
30	69.80	64.90	60.00	56.00
31	69.90	65.00	60.10	56.20
32	69.70	65.20	60.30	56.30
33	68.80	62.50	58.00	53.70
34	69.50	63.50	59.00	54.60
35	69.70	63.40	59.20	54.50
36	69.30	63.30	58.80	54.20
37	69.40	63.60	59.00	54.20
38	69.60	63.70	59.10	54.50
39	67.80	62.00	57.70	52.70
40	69.70	63.80	59.20	54.80
41	69.20	63.50	58.40	54.20
42	69.30	64.00	58.20	54.10
43	69.80	64.50	58.70	55.00

TABLE 14: PIEZOMETER READINGS FOR TAINTER GATE, IN CM.

REYNOLDS NO.= 0.56E+06, Y/Y_0 = .20

h_G/Y_0 : PIEZOMETER NO.	1.32	1.13	0.98	0.82
1	75.00	70.00	65.10	60.80
2	74.70	69.50	64.60	60.50
3	74.70	69.50	64.60	60.50
4	74.70	69.50	64.60	60.50
5	74.80	69.60	64.70	60.60
6	69.50	64.50	59.60	55.20
7	69.30	64.00	61.20	60.20
8	68.70	63.50	60.70	60.10
9	66.80	61.50	59.00	59.80
10	65.40	59.60	57.60	59.80
11	66.20	60.40	58.30	59.70
12	57.40	61.80	69.50	60.30
13	69.00	62.20	61.10	60.60
14	74.50	69.20	64.50	60.70
15	74.80	69.70	65.00	60.60
16	74.80	69.80	64.90	60.50
17	74.60	69.70	64.80	60.50
18	74.80	69.70	64.70	60.40
19	74.30	69.60	64.60	60.40
20	74.10	69.30	64.50	60.40
21	73.90	69.00	64.30	60.30
22	73.60	68.70	64.10	60.00
23	72.80	67.80	63.20	58.80
24	71.30	66.30	61.60	57.30
25	74.60	69.70	65.80	60.70
26	74.40	69.50	65.60	60.50
27	74.00	69.00	65.10	60.10
28	73.20	68.50	64.60	59.60
29	73.10	68.00	64.40	59.30
30	72.30	67.00	63.40	58.50
31	71.30	65.80	62.20	57.70
32	70.30	65.00	61.20	56.50
33	68.50	63.30	59.70	55.00
34	69.30	64.50	60.70	55.90
35	69.00	64.30	60.50	55.80
36	68.60	64.00	60.00	55.00
37	70.50	65.20	61.30	55.90
38	69.40	64.10	60.30	55.00
39	68.00	63.00	58.10	53.80
40	69.40	64.10	60.30	55.00
41	68.80	63.50	59.50	54.70
42	68.90	63.60	59.70	54.80
43	69.50	64.20	60.40	55.10

TABLE 15: PIEZOMETER READINGS FOR TAINTER GATE, IN CM.

REYNOLDS NO. = 0.56E+06, Y/Y_0 = .30

h_G/y_0 : / PIEZOMETER NO.	1.32	1.13	0.98	0.82
1	75.00	70.00	65.00	60.10
2	74.20	69.20	64.30	59.60
3	74.30	69.30	64.30	59.60
4	74.30	69.30	64.40	59.60
5	74.40	69.40	64.50	59.70
6	69.50	64.30	59.50	54.50
7	70.00	66.70	64.60	59.70
8	70.00	66.70	64.60	59.70
9	69.60	66.50	64.60	59.70
10	68.90	66.00	64.60	59.70
11	67.80	65.20	64.50	59.70
12	65.70	63.70	64.00	59.50
13	65.60	63.60	64.60	59.70
14	67.00	64.60	64.60	59.70
15	68.20	65.40	64.60	59.80
16	74.00	69.40	64.70	59.80
17	74.70	69.70	64.80	59.80
18	74.80	69.80	64.80	59.90
19	74.60	69.60	64.60	59.70
20	74.30	69.30	64.30	59.40
21	73.90	68.90	64.00	59.10
22	73.60	68.60	63.70	58.70
23	72.80	67.70	62.90	57.80
24	70.80	65.50	60.90	56.00
25	74.30	69.00	64.30	59.50
26	74.00	68.60	64.00	59.00
27	73.00	68.00	63.10	58.20
28	72.50	67.60	62.50	57.50
29	71.60	67.50	62.00	57.00
30	70.80	66.50	61.50	56.50
31	70.60	65.00	61.20	56.10
32	70.20	64.00	60.50	56.70
33	70.00	64.70	61.20	55.00
34	70.60	64.50	61.50	55.80
35	70.50	64.00	60.50	55.50
36	69.80	65.50	60.80	54.80
37	70.60	65.00	61.50	55.50
38	69.60	64.50	60.00	54.00
39	68.00	63.00	58.00	53.00
40	69.60	64.50	60.00	54.00
41	69.10	63.60	59.50	53.50
42	69.20	63.70	59.60	53.60
43	69.60	64.50	60.20	54.00

TABLE 16: PIEZOMETER READINGS FOR TAINTER GATE, IN CM.

REYNOLDS NO.= 0.56E+06, Y/Y_0 = .40

h_G/Y_0 : PIEZOMETER NO.	1.32	1.13	0.98	0.82
1	74.50	70.00	65.00	60.50
2	73.60	69.00	64.30	59.70
3	73.60	69.00	64.30	59.70
4	73.60	69.00	64.30	59.70
5	73.70	69.10	64.40	59.80
6	69.50	64.50	59.50	54.80
7	70.00	68.50	64.40	60.00
8	70.30	68.50	64.40	60.00
9	70.30	68.50	64.30	60.00
10	70.10	68.40	64.30	60.00
11	69.90	68.40	64.30	60.00
12	58.90	68.00	63.90	59.70
13	68.00	68.00	64.20	60.00
14	66.70	67.40	64.20	60.00
15	67.40	67.70	64.20	60.10
16	68.50	68.00	64.20	60.10
17	71.10	68.60	64.70	60.15
18	74.30	69.80	64.80	60.20
19	74.30	69.70	64.60	60.30
20	74.10	69.50	64.20	60.10
21	74.00	69.10	63.80	59.70
22	73.50	68.80	63.00	59.30
23	72.30	68.00	60.80	58.40
24	70.70	65.50	63.80	56.00
25	73.50	68.50	63.20	59.00
26	73.00	68.30	62.00	58.50
27	72.00	67.20	61.50	57.50
28	70.30	67.00	61.40	57.00
29	71.30	66.60	61.20	56.90
30	71.00	66.00	61.00	56.50
31	70.80	65.30	60.80	56.20
32	70.50	65.30	60.70	56.10
33	69.20	65.00	69.50	55.00
34	69.70	65.50	60.40	55.50
35	69.50	65.40	60.20	55.40
36	69.30	65.20	60.00	55.20
37	69.80	64.50	59.80	55.00
38	69.40	63.50	59.00	54.50
39	68.30	63.00	58.00	53.60
40	69.20	63.50	59.00	54.60
41	69.10	63.10	58.30	54.00
42	69.00	63.20	58.40	54.10
43	69.70	63.70	59.00	54.60

TABLE 17: PIEZOMETER READINGS FOR TAINTER GATE, IN CM.

REYNOLDS NO. = 0.56E+06, Y/Y_0 = .50

h_g/Y_0: PIEZOMETER NO.	1.32	1.13	0.98	0.82
1	75.50	69.50	65.00	60.60
2	74.50	68.40	64.00	59.60
3	74.60	68.50	64.10	59.70
4	74.60	68.50	64.10	59.70
5	74.70	68.60	64.20	59.80
6	69.70	64.40	69.50	54.80
7	70.40	68.50	64.50	60.00
8	70.50	68.50	64.50	60.00
9	70.70	68.50	64.40	60.00
10	70.70	68.50	64.40	60.00
11	70.40	68.40	64.50	60.00
12	69.50	68.00	64.10	59.70
13	68.80	68.10	64.20	60.00
14	67.20	68.10	64.20	60.00
15	67.30	68.20	64.30	60.00
16	68.30	68.30	64.30	60.00
17	69.40	68.40	64.30	60.00
18	74.60	69.20	64.70	60.20
19	75.30	69.40	64.80	60.30
20	74.90	69.20	64.70	60.20
21	74.60	68.70	64.20	59.80
22	74.10	68.40	63.70	59.30
23	73.30	67.40	63.00	58.40
24	70.20	65.10	61.00	56.40
25	74.40	68.50	64.20	59.20
26	73.90	68.00	64.00	59.00
27	72.70	66.70	63.00	57.70
28	72.60	66.70	62.50	57.40
29	71.30	65.70	62.00	57.10
30	71.00	65.00	61.50	56.50
31	70.80	64.90	61.00	56.00
32	70.60	64.70	60.80	55.90
33	69.50	64.20	60.00	55.00
34	70.00	64.00	60.50	55.50
35	69.80	63.80	60.20	55.30
36	69.20	63.10	60.40	55.00
37	70.00	64.50	60.60	55.60
38	69.50	63.50	59.50	55.00
39	68.40	62.00	58.00	53.50
40	69.30	63.50	59.50	55.00
41	69.00	62.70	59.20	54.30
42	69.10	62.80	59.30	54.40
43	70.00	63.50	59.80	55.20

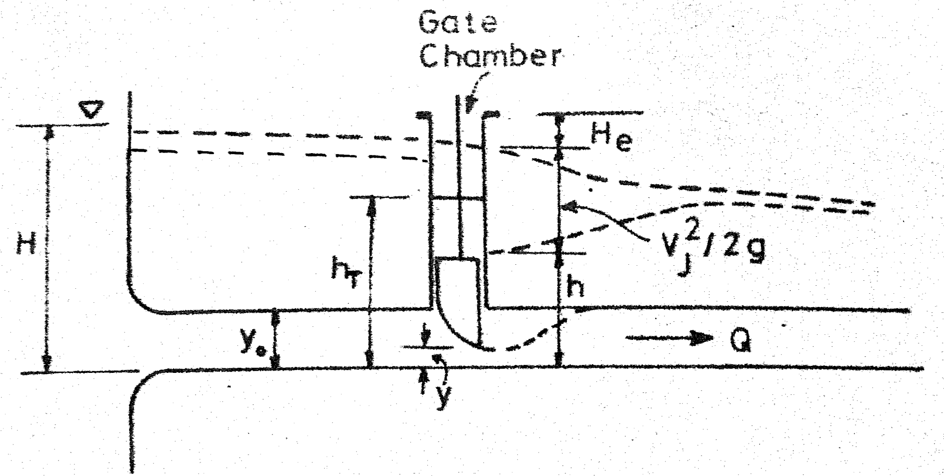

FIG. 1 (a) REPRESENTATION OF TYPICAL VERTICAL LIFT GATE ARRANGEMENT UNDER SUBMERGED FLOW CONDITIONS

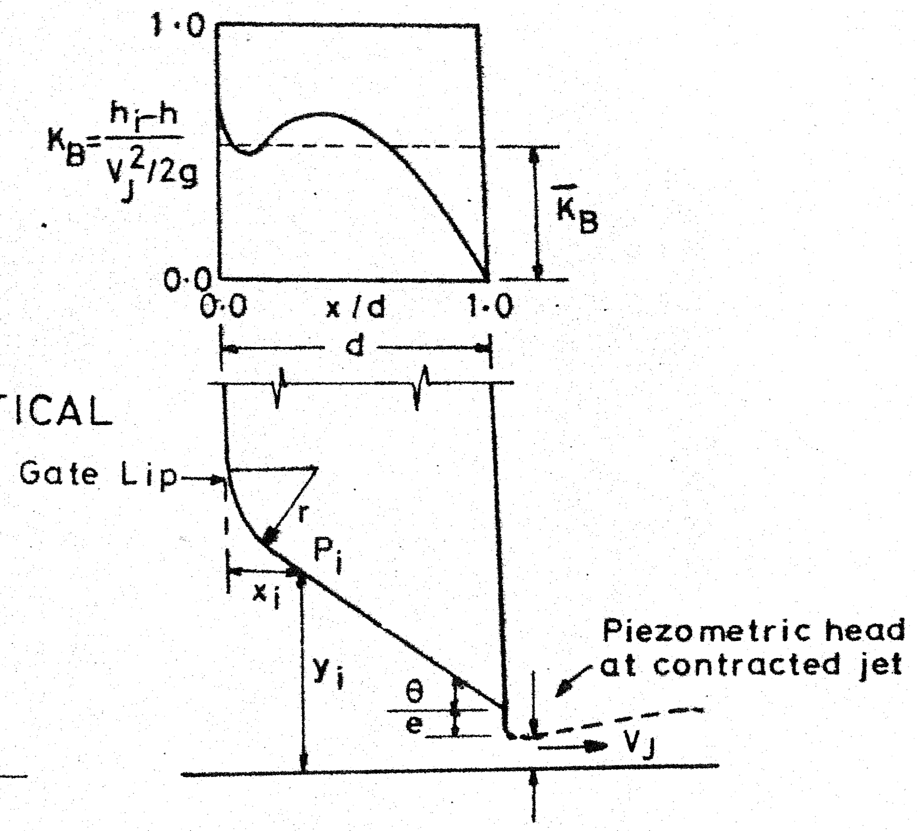

FIG. 1 (b) DEFINITION SKETCH FOR THE MEAN VALUE OF $\overline{K}_B$

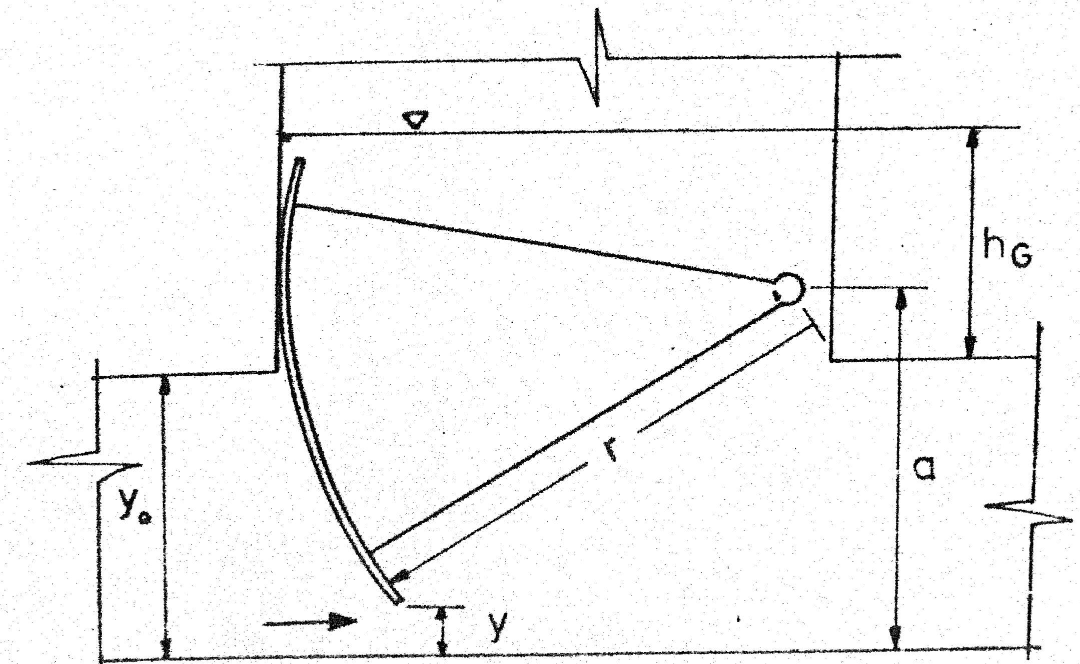

FIG. 1 (c) DEFINITION SKETCH FOR TAINTER GATE ARRANGEMENT

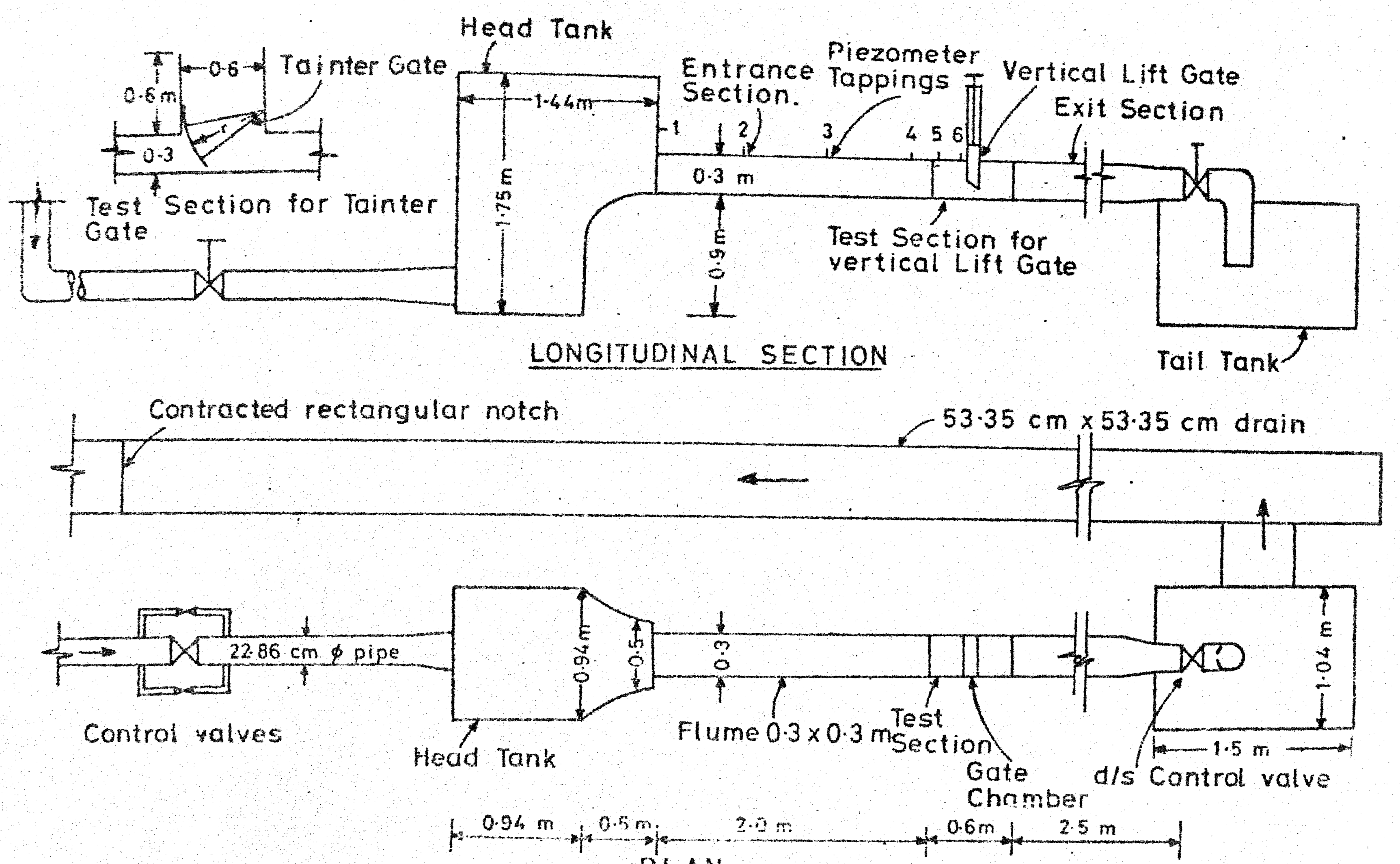

Fig. 2 Schematic view of the experimental equipment

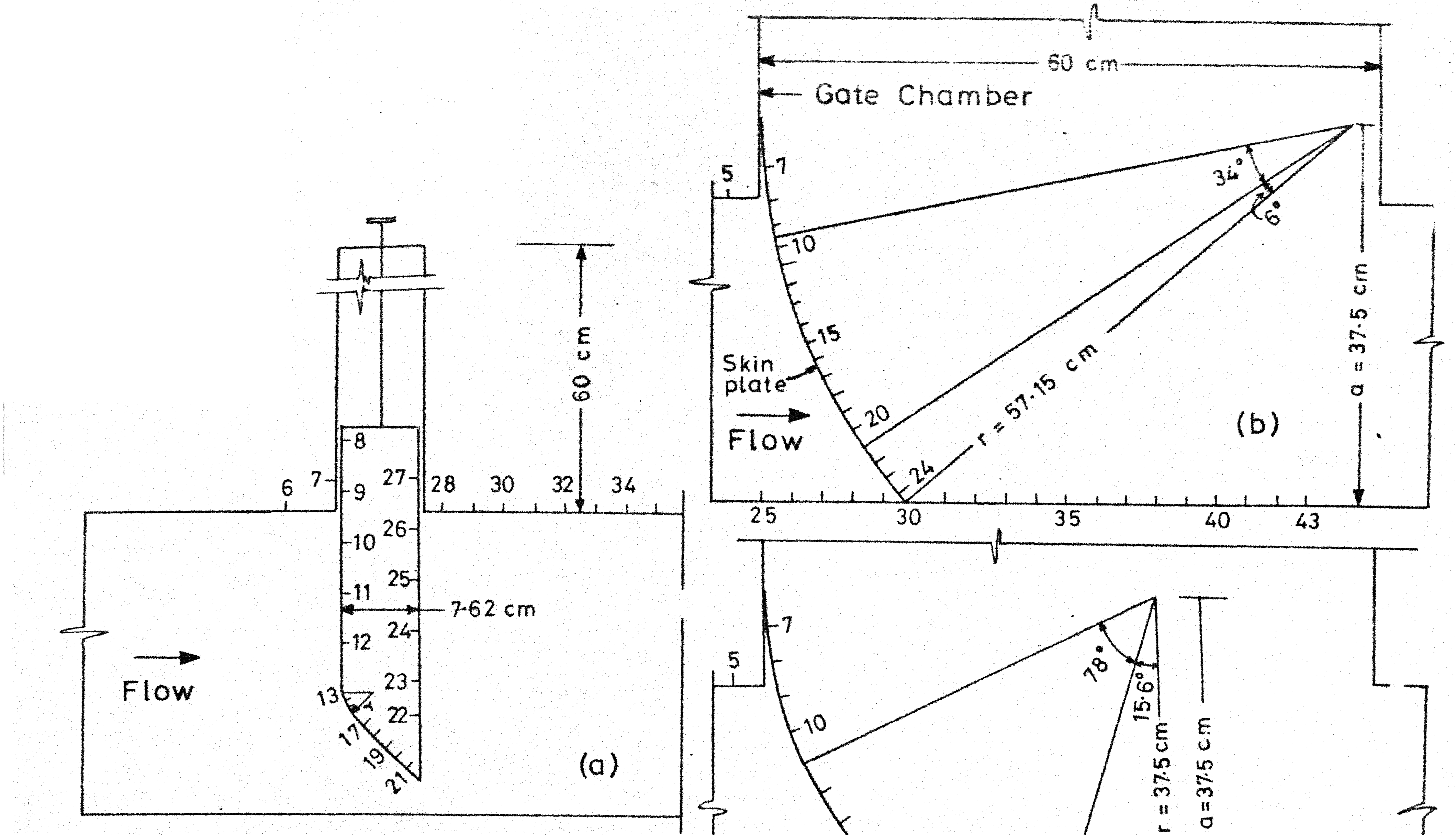

Fig. 3 Location of piezometer tappings for
(a) Vertical Lift gate
(b) Tainter gate with $r/y_o = 1{\cdot}875$
(c) Tainter gate with $r/y_o = 1{\cdot}25$

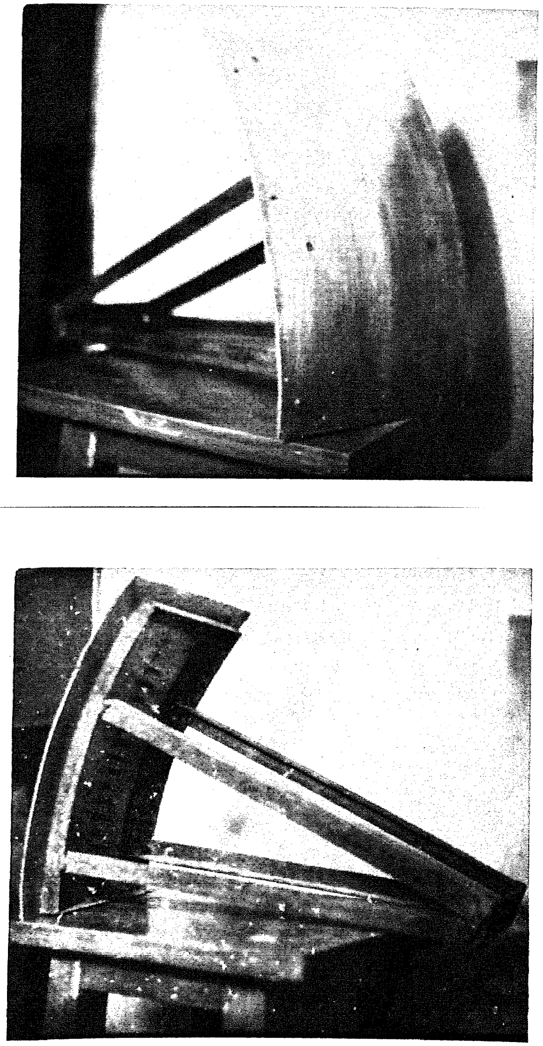

Fig. 4(b) Tainter Gate, $r/y_o = 1.875$

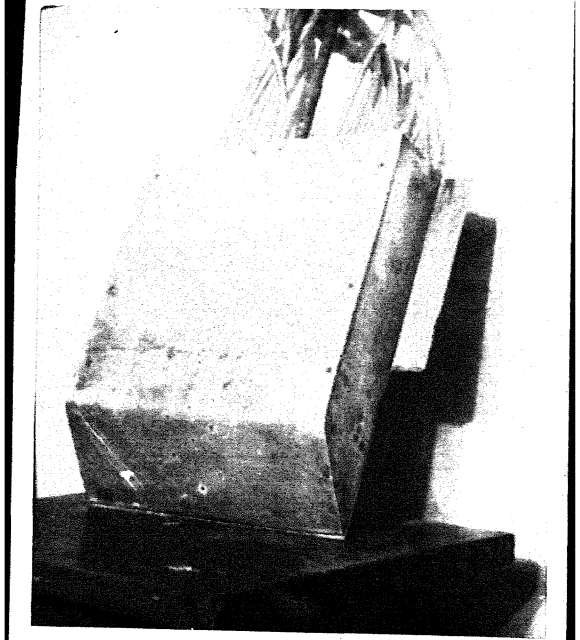

Fig. 4(a) Vertical Lift Gate

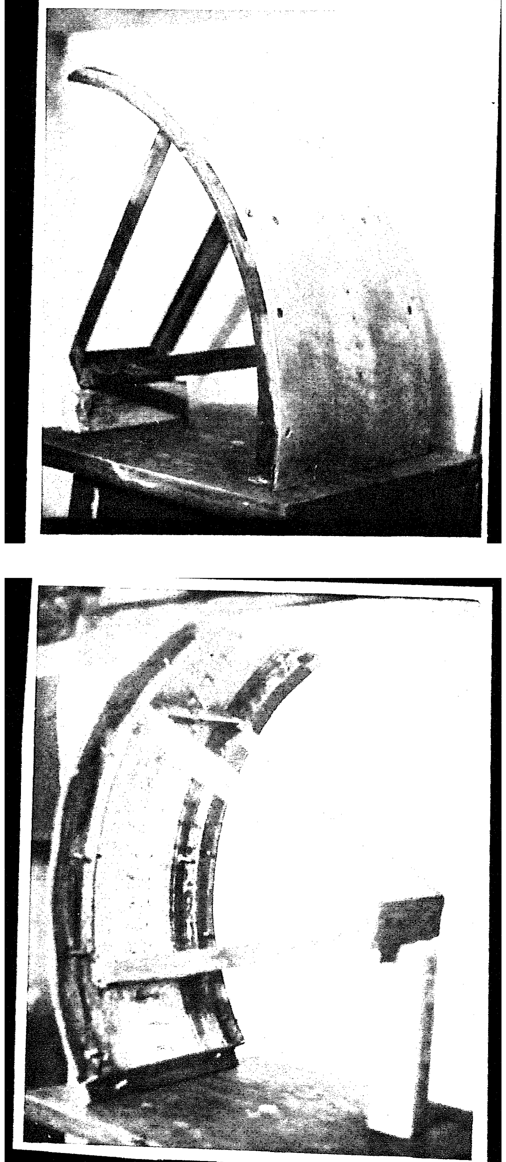

Fig. 4(c) Tainter Gate, $r/y_o = 1.25$

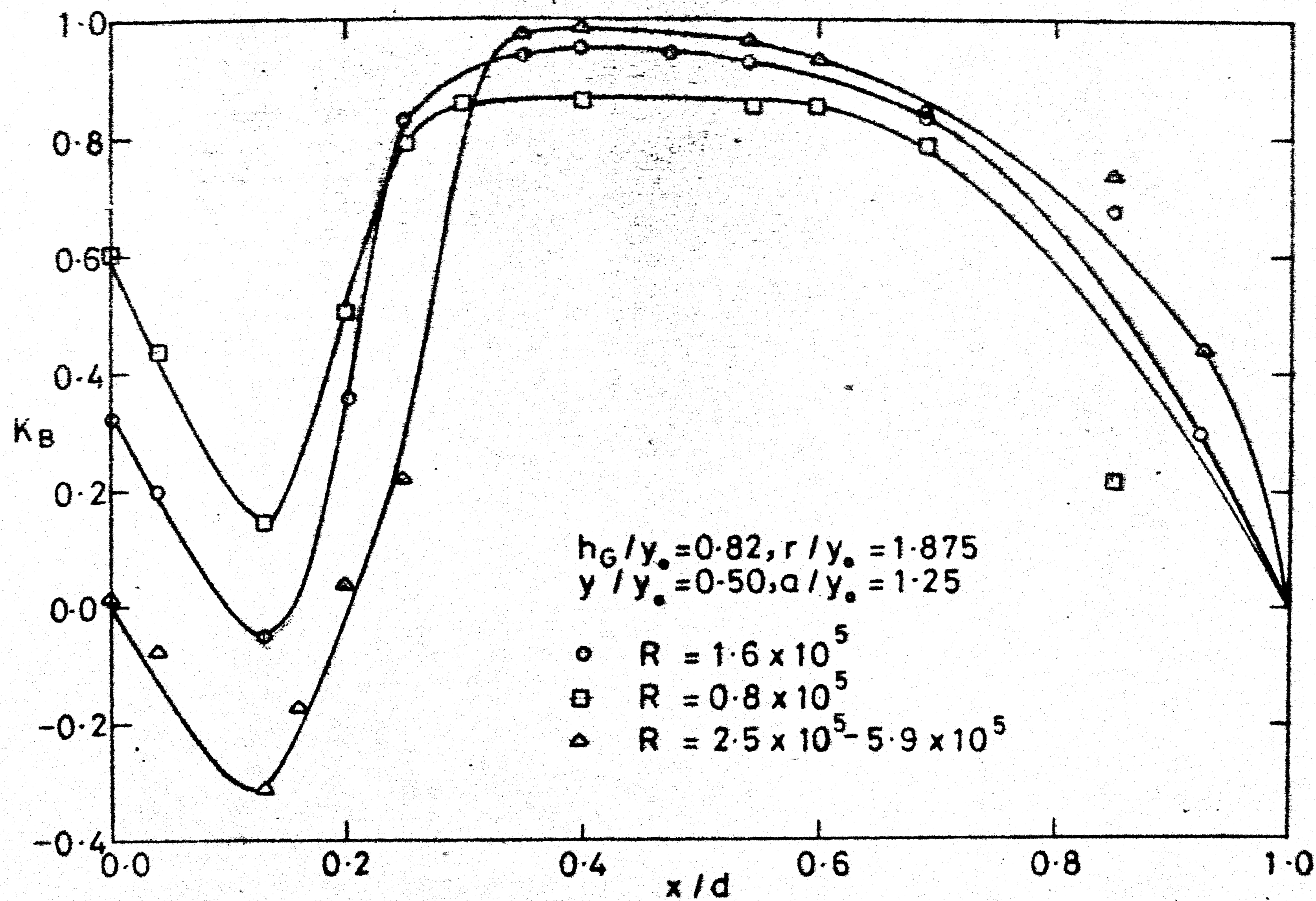

Fig. 6 Variation of K_B with x / d for different Reynolds Numbers for Tainter Gate with $r / y_* = 1·875$

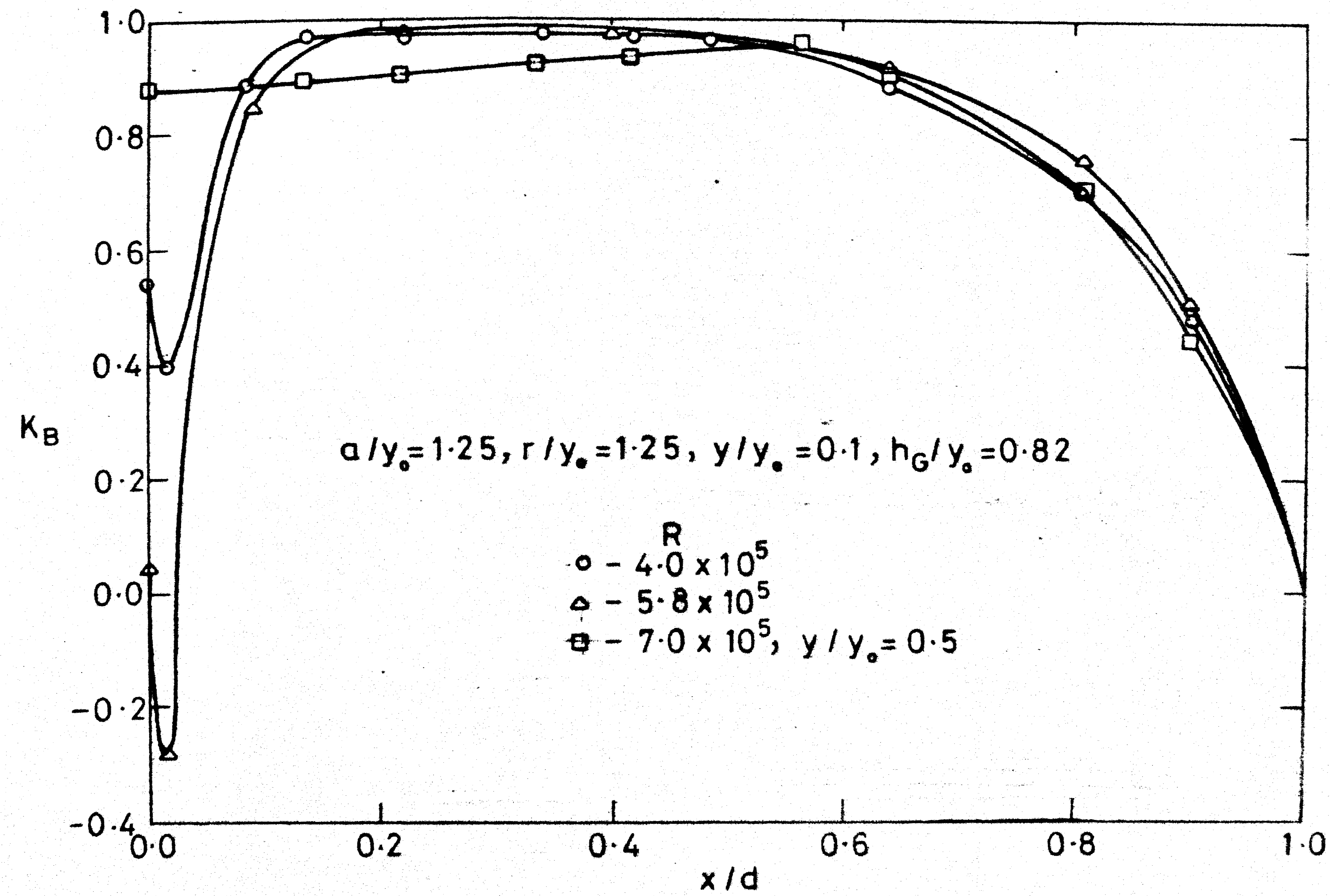

Fig.7 Variation of K_B with x/d for different Reynolds Numbers for Tainter Gate with $r/y_o = 1{\cdot}25$

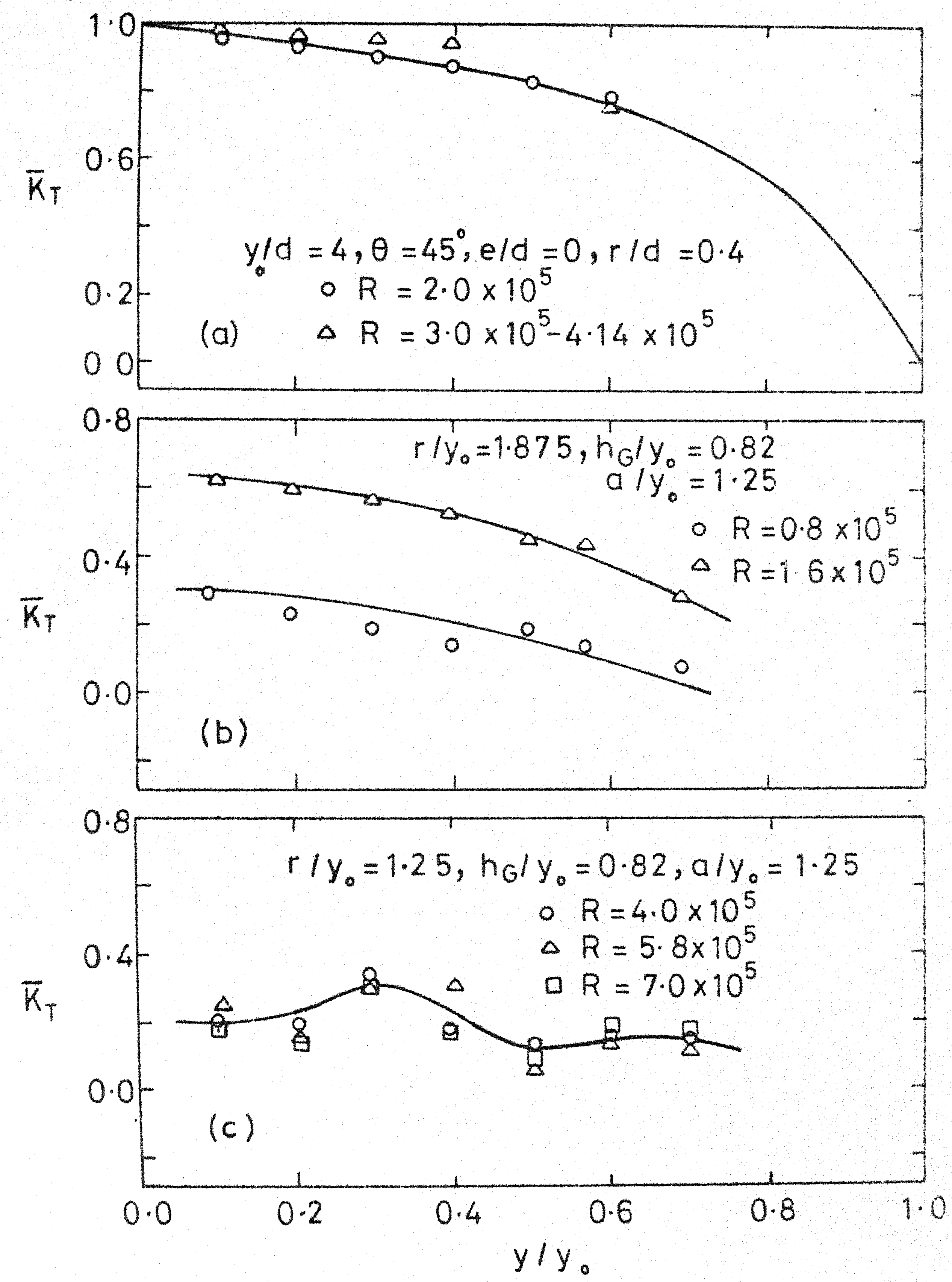

Fig. 8 Variation of $\overline{K}_T$ with relative gate opening y/y_o for (a) Vertical Lift gate
(b) Tainter gate with $r/y_o = 1·875$
(c) Tainter gate with $r/y_o = 1·25$

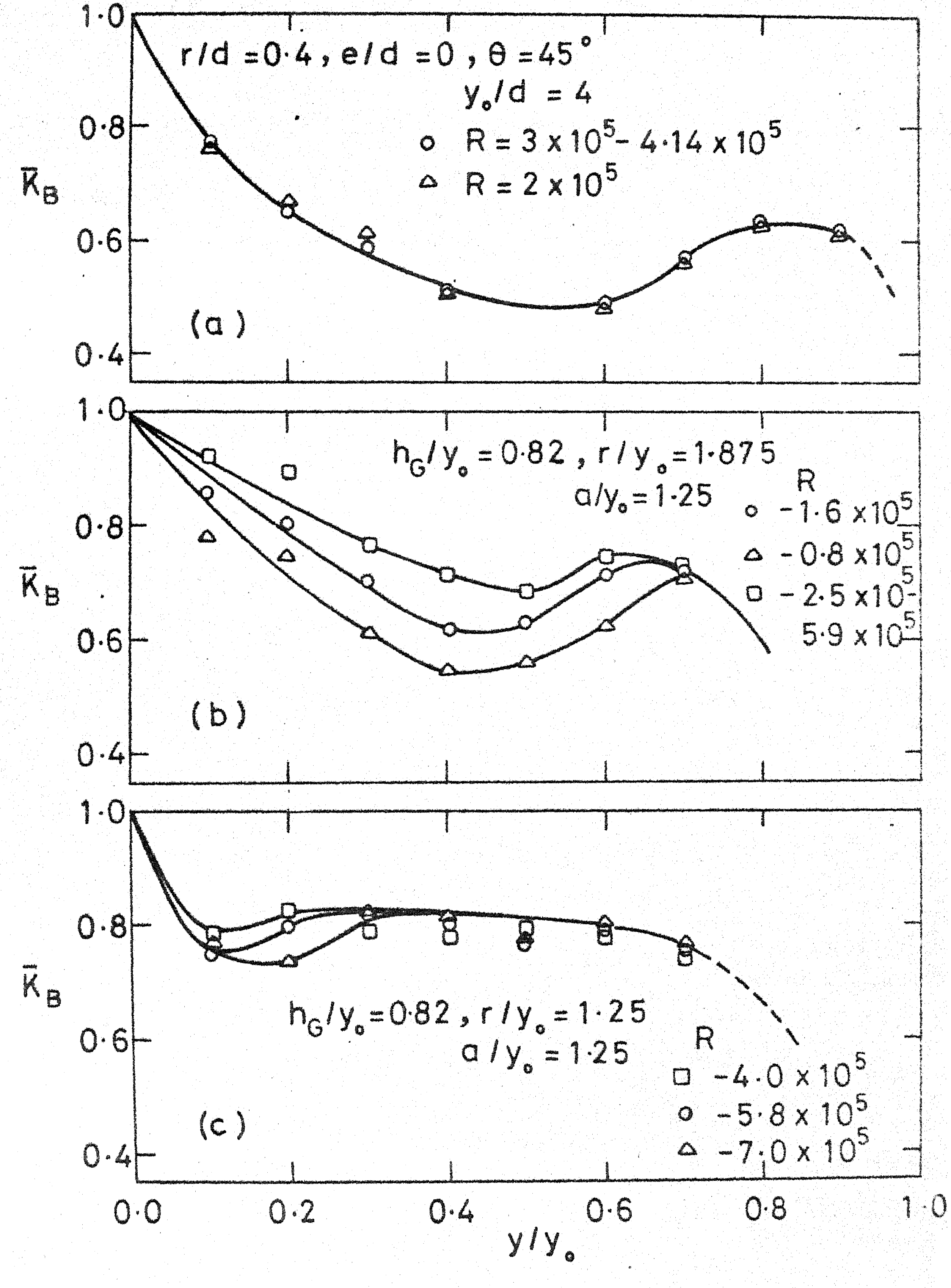

Fig. 9 Variation of $\overline{K}_B$ with Reynolds Numbers for (a) Vertical Lift gate
(b) Tainter gate with r/y_o = 1·875
(c) Tainter gate with r/y_o = 1·25

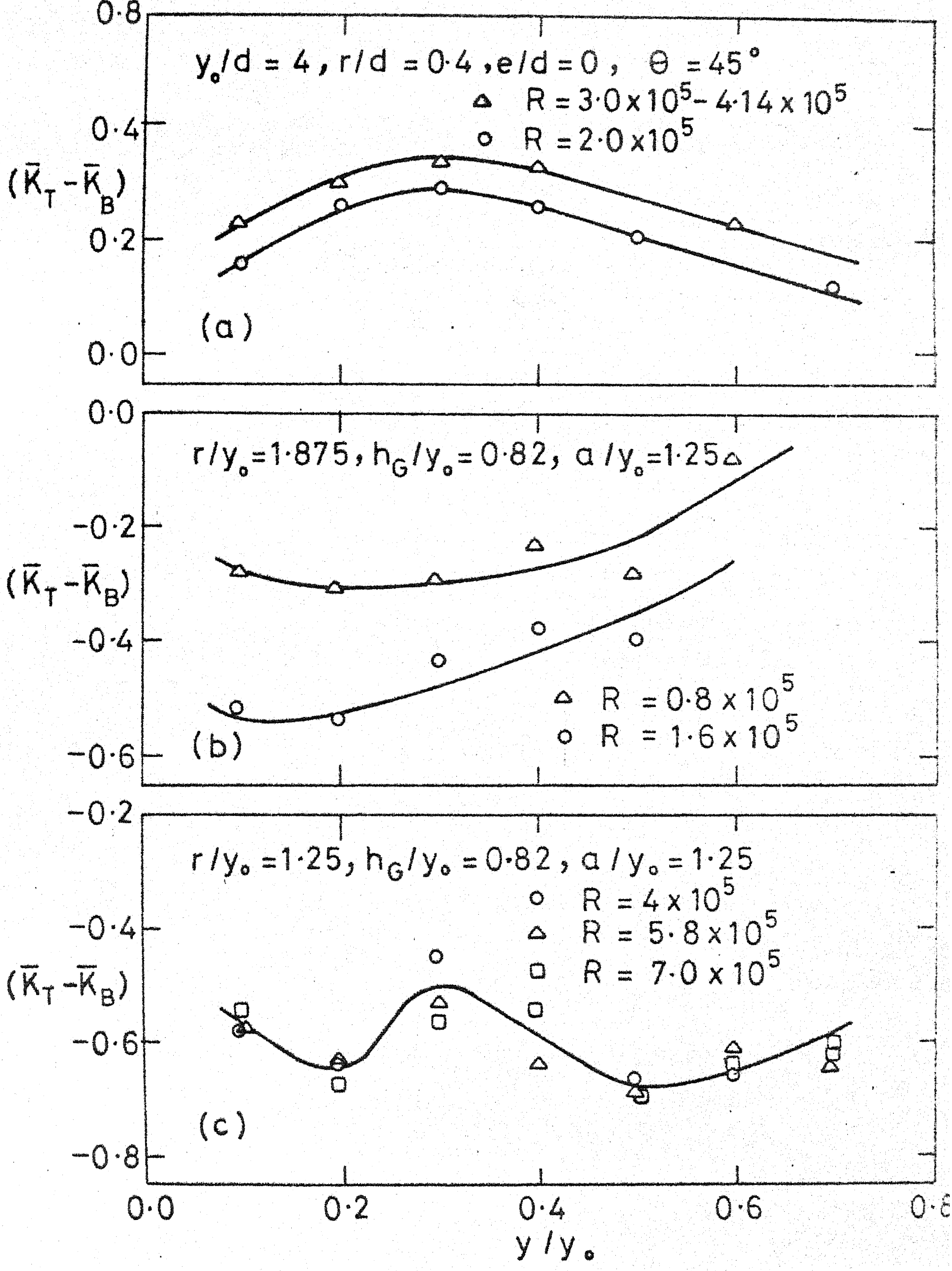

Fig. 10 Variation of $(\bar{K}_T - \bar{K}_B)$ with y/y_0 for
(a) Vertical Lift gate
(b) Tainter gate with $r/y_0 = 1·875$
(c) Tainter gate with $r/y_0 = 1·25$

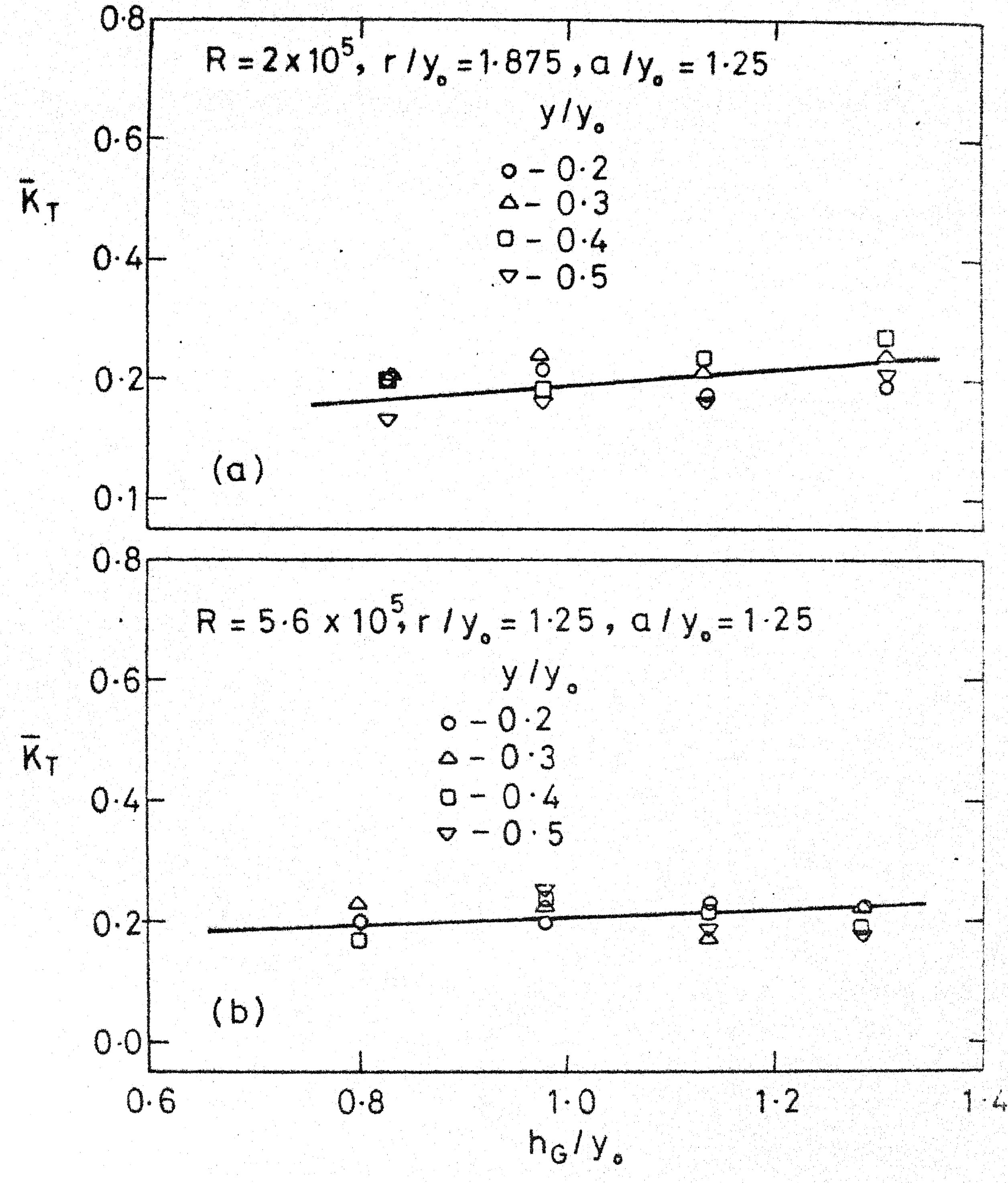

Fig. 11 Variation of $\bar{K}_T$ with h_G/y_o for tainter Gates

(a) $r/y_o = 1{\cdot}875$

(b) $r/y_o = 1{\cdot}25$

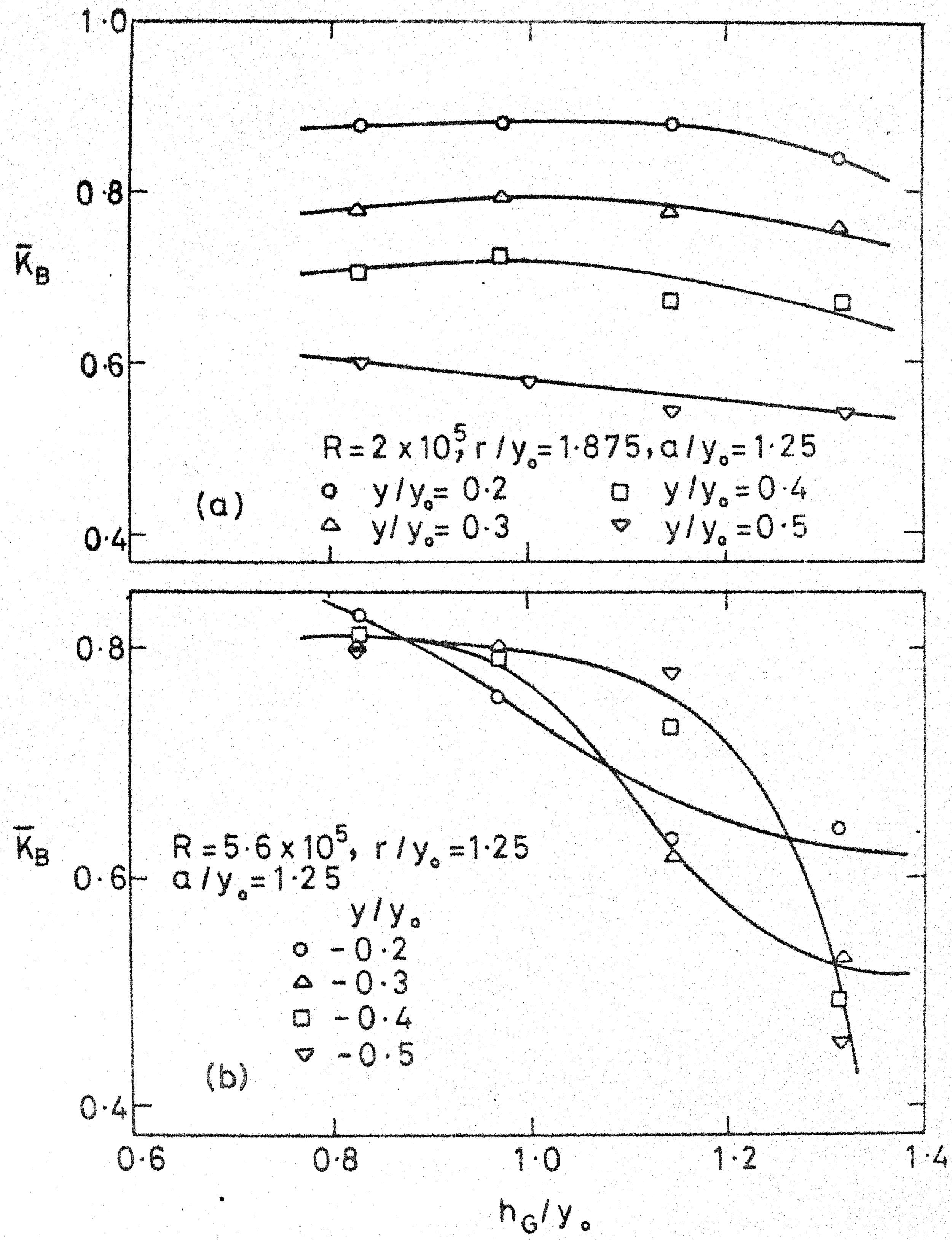

Fig. 12 Variation of $\bar{K}_B$ with h_G/y_o for Tainter Gates

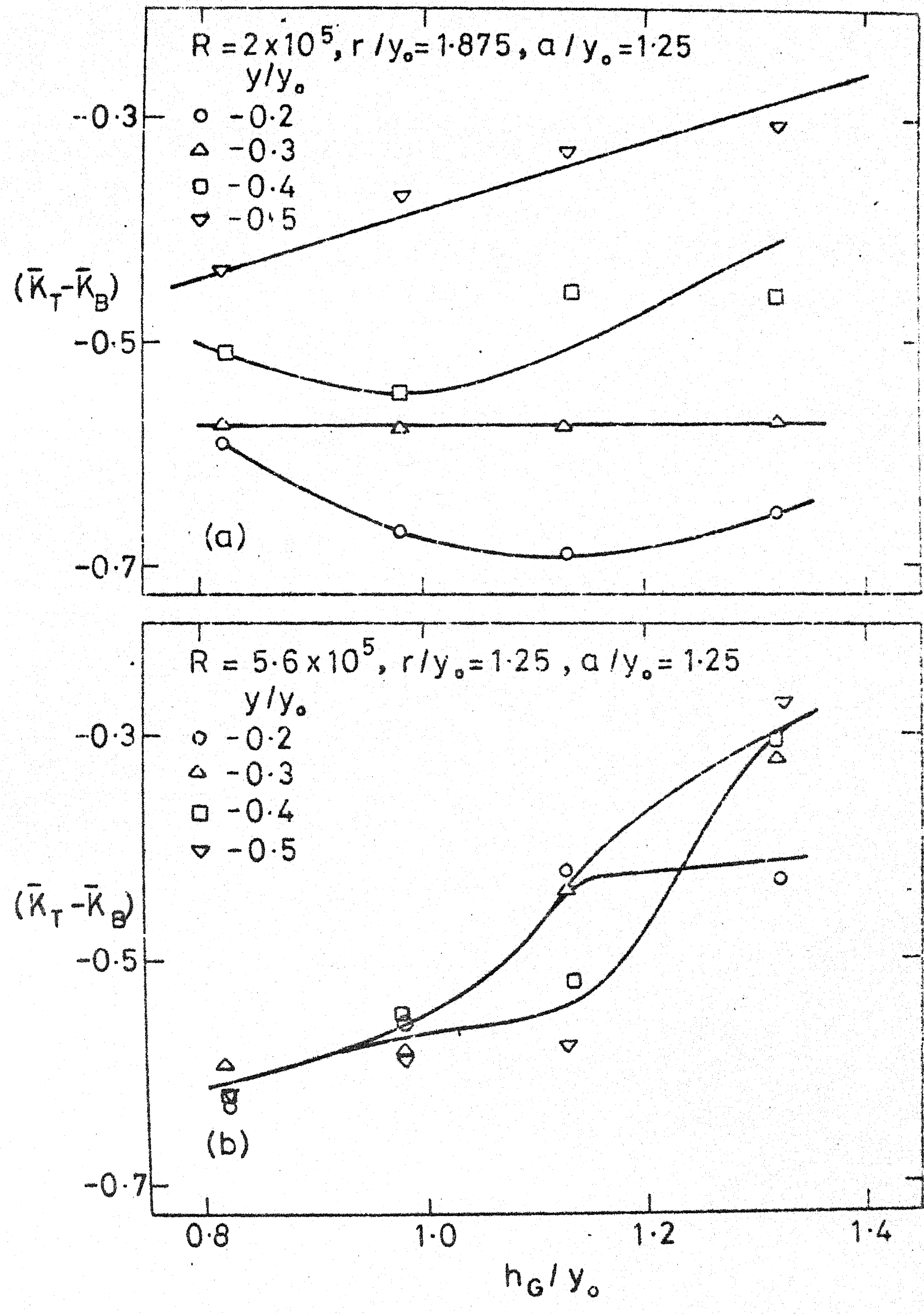

Fig. 13 Variation of $(\bar{K}_T - \bar{K}_B)$ with h_G/y_0 for Tainter Gates

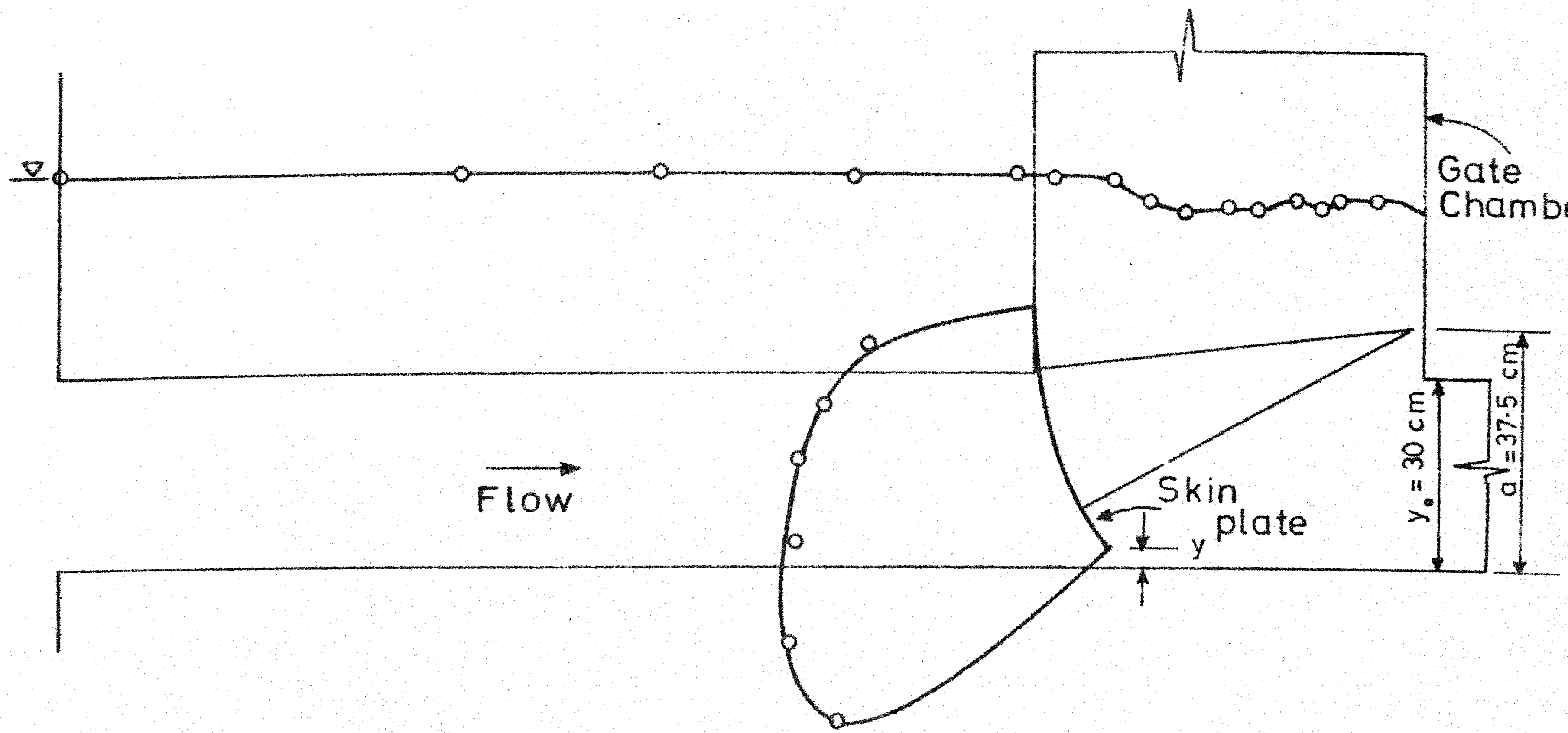

Fig.14 Variation of pressure head along the conduit and on the tainter gate with $r/y_o = 1{\cdot}875$